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Loose - Particle Detection in Microelectronic Devices

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ABSTRACT

The work described constitues an evaluation of the test procedures and apparatus specified in MIL-STD-883, Test Method 2020, Particle Impact Noise Detection Test. The major experimental effort described - a comparison of procedures and apparatus - is based on the use of specially prepared specimen device packages known either to have or not to have a particle present. Other experimental efforts reported include characterization of the accelerations imparted to a specimen device by pre- and co-shock apparatus, a brief study of the effectiveness of couplant materials in transmitting mechanical energy to the specimen device, and a comparison of the output signal level from four different ultrasonic detection transducers under otherwise identical test conditions. As part of the plan of work, 252 of the specially prepared devices, representing six package types, were characterized (as containing particles or not) by several test procedures in order to provide a set of specimens for use by the sponsor in a proposed interlaboratory evaluation of PIND testing. Problems associated with this effort are discussed. Results of the work are presented, together with conclusions and recommendations for further work. A result of interest is that the acceleration imparted by the single sample of the pre-test shock apparatus tested is on the order of 1.5 times the maximum specified by the Test Method.

Keywords: Acoustic emission; couplant; co-shock; detection; electronic package; impact noise; microcircuit device; particle detection; particle impact noise detection; PIND; pre-shock; seeded specimens; transducer.

EXECUTIVE SUMMARY

Particle-impact noise detection (PIND) is a widely used means of detecting the presence of particles in packaged microelectronic devices for critical applications. The basic PIND principle is that when a specimen device package containing a free particle is shaken, the high-frequency acoustic noise from the resulting impacts between the particle and the package interior may be detected by a suitable transducer onto which the specimen is mounted. A major difficulty with the PIND technique is that particles may be immobilized, or "locked up," during testing and at a later time become free, perhaps during operation of the device at a time when simultaneous contact between a free conductive particle (for example, from the bonding process) and conductive elements may result in short-circuit failure of the device.

The work described constitutes an evaluation of the test procedures and apparatus specified in MIL-STD-883, Test Method 2020, Particle Impact Noise Detection Test. The major experimental effort described -- a comparison of procedures and apparatus -- is based on the use of specially prepared specimen device packages known either to have or not to have a particle present.

The intent of the work was not to provide in any sense a definitive study of PIND procedures, nor was it to devise an exceptionally ingenious method that would solve "the" PIND problem. As an index to the state of knowledge in the PIND area, consider the following: It has been estimated that a thorough examination of one aspect of PIND -- the role of electrostatic mechanisms in the immobilization and release of particles -- would require over five man years to achieve basic understanding with no guarantee of any information being developed that could be used directly in PIND testing (although it is likely that information that could be used by microelectronic device designers would be generated). As to the existence of a single PIND problem, for each device technology there can be many compositions, shapes, and sizes of foreign particles, and individual device types will have differing microgeometries within a single product-line grouping of similar devices.

It was therefore recognized at the outset that the NBS contribution would have practical emphasis and concentrate on hands-on evaluation.

Accordingly a preliminary line of work was established to provide NBS staff with operating experience in PIND testing according to Test Method 2020; this work followed earlier work for SAMSO which was concerned with a preliminary evaluation of couplant performance [1,2].[1]

The experiments carried out in this stage of the work are described in 2.3.1, with results given in 3.4. This plan of divided description of tests and results is followed throughout to provide as clear as possible a distinction between the experiments themselves (section 2) and the information resulting from these experiments (section 3).

A result of this early work was the development of a technique for comparing the detection capability of various methods and configurations and settings of apparatus. In this technique, the output of the ultrasonic detection transducer is fed to the vertical amplifier of an oscilloscope for which the horizontal deflection signal is the sweep sawtooth voltage corresponding to the drive frequency of the shaker used to excite the specimen device. For comparing the effects of different excitation frequencies, the acceleration level is held constant and the shaker frequency is swept, so that the resulting oscilloscope trace is a plot of detection signal amplitude as a function of excitation frequency.

Other results from the first stage of work carried out on device packages without dice or leads relate to a correlation between the test acceleration level and particle lock-up. The most effective acceleration level appears to be highly device-dependent, a finding that was substantiated in the main body of tests on specially prepared devices.

These second-stage tests were carried out on 252 specimen devices, representing six package types and a number of different seed particle sizes in several materials (see table 2 for detailed list); these devices were characterized by the commercial supplier as either intentionally seeded with a single particle or free from any particle that could result in detection in a PIND run. (It should be noted that particles such as aluminum

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[1] Figures in brackets refer to literature references given in Section 5.

spheres 0.025 mm in diameter have a low enough mass -- nominally 0.02 μg -- that the supplier, in common with other test operators, did not regard Test Method 2020 procedures as adequate for their detection, even if free.) These seeded and unseeded specimens were the subject of seven trials in the NBS laboratory and, later, of three additional trials in the supplier's facility (Appendix 1 constitutes detailed information on the results from each trial; summaries are presented in table 5 for NBS and table 7 for the supplier).

After several of the NBS trials were completed, it became obvious that according to the supplier's characterization (seeded or unseeded) the NBS results were showing low detection scores for seeded specimens and, even less understandably, detections in unseeded ones. There were a number of possible explanations; these are examined in detail in 2.1.4. Although it was not possible to arrive at a definitive explanation of the anomalies, it is likely that some event affected the specimens between the time they were tested prior to shipment to NBS by the supplier and the time of the first NBS trial. It is noteworthy that the three post-NBS trials conducted by the supplier (at his suggestion, in an attempt to resolve uncertainties) are in better agreement with the NBS results than with his initial characterization. A more comprehensive discussion of these points is given in 3.1.

A part of the work was to characterize the shock acceleration imparted by a pre-test shock and a co-shock apparatus, both being commercially available devices (co-shock refers to the application of shock acceleration while the specimen is being driven by the shaker). The evaluation of the pre-test shock apparatus was carried out in the light of the suggestion that some event had occured to change the characterization of the specimen devices, as all NBS trials involve applying pre-test shock for each specimen with the single sample of apparatus purchased for the purpose. The results, discussed in detail in 3.3.1, suggest that the apparatus is likely to provide peak acceleration on the order of 1.5 times the maximum specified by the Test Method. Whether this excess is sufficient to free or produce new particles or to immobilize free ones must remain conjectural. The supplier did report that in at least one instance a broken lead was found when an unseeded specimen was opened for inspection. (Only a few specimens were available for direct examination, as a major purpose of the specimens was to serve as a well-characterized set of specimens for use by the sponsor in a proposed inter-laboratory evaluation of PIND testing.)

Descriptions of other experiments and their results are considered to be principally matters of detail and are therefore not specifically identified in this summary.

The chief recommendation applying to the development of the Test Method, given in 4.1, is that semi-automatic apparatus be used to avoid difficulties with operator fatigue, judged to be severe in a production line testing operation. It should be pointed out, however, that the NBS results, even when corrected as suggested in 3.1, do not show high detectability scores even for the special particles used as seeds, which may not be (indeed probably are not) typical of the free particles enclosed in sealed micro-electronic devices on the production line. As device geometries grow smaller, the size of an "acceptable" conducting particle will drop, yet there is no guarantee that the mechanisms producing particles will compensate by generating smaller particles, although if this were the case present-day PIND procedures would not be likely to detect them. The point is simply that the PIND art is an uncertain one; the relatively limited NBS trials (compared to operators who have tested tens of thousands of devices) can perhaps best serve to provide a caution relating to overreliance on PIND as a method of qualification. It is in this light that the following report should be read.

1. INTRODUCTION

1.1 Background

The work contained in this report was sponsored by the National Aeronautics and Space Administration under purchase order S39193-B.

For over a decade, various particle-impact noise detection (PIND) methods have been used in the electronics industry as a product assurance method of detecting the presence of particles in packaged microelectronic devices [3]. The basic PIND principle is that when a specimen device package containing a free particle is shaken, the high-frequency acoustic noise from the resulting impacts between the particle and the package interior may be detected by a suitable transducer onto which the specimen is mounted. A major difficulty with the PIND technique is that particles may be immobilized, or "locked up," during testing and at a later time become free, perhaps during operational use of the device at a time when simultaneous contact between a free conductive particle (for example from the bonding process) and conductive elements may result in short-circuit failure of the device.

MIL-STD-883 Test Method 2020, Particle-Impact Noise Detection Test, developed under the aegis of the Defense Logistics Agency, is intended to encompass the best PIND technology suitable for production line testing of devices. The Test Method is therefore continuously subject to analysis and review for improvement.

The work described constitutes an evaluation of the test procedures and apparatus of Test Method 2020 and, more specifically, responds to the following tasks:

(1) Evaluate existing PIND procedures, apparatus, and techniques using specially prepared microelectronic packages known either to contain or not to contain a seed particle.

(2) Characterize the accelerations imparted to a specimen device by a selected commercially available PIND system incorporating means for solenoid-generated co-shock and a low-impedance output to the detection system.

(3) Evaluate co-shock methods experimentally; on the basis of experience from this evaluation, propose modifications or new techniques.

(4) On the basis of the experimental work, investigate other aspects of PIND procedures that appear to be of interest, such as noise levels in the detection signal, and the like.

(5) Provide suitable seeded and unseeded specimen devices for the evaluation of task 1, including devices in the following configurations: TO-5, TO-18, TO-3, 16-lead ceramic dual-in-line, 14- or 16-lead ceramic flatpack with metal lid, and 14- or 16-lead ceramic flatpack with ceramic lid, with the following stipulations:

5.1 Each seeded package shall contain only one particle;

5.2 All devices shall be fabricated and inspected in a manner that ensures there is little chance of a non-seed particle remaining in the package following closure;

5.3 Each package shall contain a die and all customary wire lead connections for the device;

5.4 Seed particles primarily shall be in the form of gold, aluminum, lead (or solder), and silicon-aluminum spheres and shall cover a particle-size range from 0.025 to 0.127 mm in diameter, with a higher proportion of seed particles in the smaller sizes.

(6) Using procedures specified in Test Method 2020, test the devices of (5) to determine for each device whether a particle is or is not present. Repeat the tests several times in order to provide experimentally characterized sets of devices suitable for use in a proposed interlaboratory evaluation of PIND procedures.

1.2 General Considerations

Examination of the PIND testing literature [3] and contacts with various workers indicate that the major difficulty with PIND methods is lock-up of the particle to be detected. [4,5] Motion-picture films taken during PIND testing of a device package with a window in the lid and with a number of free particles present initially show impacts occurring with the interior of the package or the die at intervals of a few milliseconds per particle as long as the particles remain free. However, as the test time lengthens, more and more particles become immobilized. This observation illustrates one difficulty with PIND test procedures -- testing a device may result in lock-up of an initially free particle before detection occurs. If the particle were to remain immobilized, and were not short-circuiting conductive elements, or straining a bond, this situation would be acceptable. The problem is that as the details of even the most prevelant trapping mechanisms are not known (either in general or for a given device type), there is no guarantee that the particle will remain locked up, and, in fact it may become free during operation of the device, with the possibility of consequent device failure from short-circuit or other cause.

This discussion assumed that the particle to be detected was free initially; however, experience shows that the problem of freeing an initially locked-up particle (and of keeping it free long enough for detection) is severe. It may be thought that if the particle is not free, it should be left alone; the question is of course, "How free is free?" Given the state of knowledge of particle lock-up, the PIND test designer is forced to turn to the application of shock acceleration to the specimen device and to select a level of shock acceleration that will exceed the worst case to which the device is likely to be subjected during its operational life. To implement this concept, Test Method 2020 calls for a pre-test shock to be applied to all specimen devices and for a co-shock to be applied while the specimen is being excited on a shaker[2] armature if no detection signal is received initially.

In addition to pre-and co-shock acceleration levels, other parameters that affect the ability of a given PIND procedure and apparatus to detect particles

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[2] To correspond with the usage of MIL-STD-883, the sponsor has requested that the more technically precise term "vibration exciter" be replaced by the term "shaker."

include:

(1) package type, device type, and materials of construction;

(2) mass (or size) and composition of particles to be detected;

(3) duration of test;

(4) number of tests run on a given specimen device;

(5) mechanical properties of material used to "couple" specimen to ultransonic detection transducer;

(6) ultrasonic detection transducer sensitivity and frequency response;

(7) electrical noise characteristics of signal cables subject to flexing or vibration;

(8) detection system gain, frequency response, and signal noise levels;

(9) shaker acceleration level and frequency;

(10) frequency of application of co-shock acceleration; and

(11) spectral content of pre- and co-shock acceleration.

The work described below has taken these parameters into consideration.

2. EXPERIMENTAL WORK

2.1 PIND Trials

As indicated in the task statements, the main thrust of experimental work consisted of conducting trails of various PIND apparatus and procedures using specifically prepared specimen devices known to have either a single particle (hereinafter referred to as seeded) or no particle present in the sealed device package.

2.1.1 Apparatus - In actual PIND trials one of three configurations of apparatus was used, based on either one of the two commercial PIND equipments specified in Test Method 2020. Figures 1, 2, and 3 show block diagrams of the three configurations and table 1 identifies the components of the commercial PIND equipments. Photographs of apparatus are shown in figures 4 and 5. The threshold level detector was built in-house in accordance with the specifications and circuit diagram given in Test Method 2020. Also constructed in accordance with the Test Method was a "Sensitivity Test Unit," used to apply a mechanical signal to the ultrasonic detection transducer.

For all PIND trials unless specifically noted otherwise, the specimen devices were subjected to pre-test shock using the commercial apparatus (C) specified by Test Method 2020. Apparatus C consists of a hammer arranged to pivot around the end of its handle (lever) in a vertical plane. A rotatable cam engages the under surface of the lever near the pivot; rotation of the cam alternately raises and drops the lever, which action permits the lower end of the cylindrical metal hammer head to strike a metal anvil, integral with the apparatus frame. The frame, or base, also supports the cam axle and the lever pivot. A specimen device to be pre-shocked is attached to the upper end of the hammer head with the same couplant to be used in the PIND test for that device, and the cam rotated so that the hammer raises and falls once. Measurements on the shock acceleration imparted by this apparatus are reported in 3.3.1.

Test configuration 3 requires some explanation. A technique for comparing the detection capability of various methods and configurations and settings of apparatus was devised, in which the conditioned output of the ultrasonic detection transducer is fed to the vertical amplifier of an oscilloscope for which the horizontal deflection signal is the sweep sawtooth voltage corresponding to the drive frequency of the shaker used to excite the specimen device. For experiments comparing the effects of different excitation frequencies, the acceleration level is held constant and the shaker frequency is swept, so that the resulting oscilloscope trace is a plot of detection signal amplitude as a function of excitation frequency. In practice, a further refinement was required as follows. With a specimen device (known from experience to have a free particle that shows practically no tendency to lock up) in place on the ultrasonic detection transducer and the shaker and other system components energized, the vertical position of the trace and the polarity of the oscilloscope y axis preamplifier are set so that the trace appears as a series of faint vertical lines rising from a heavy base line, which represents the zero level for the detection signal. Deflection upwards thus corresponds to increasing detection signal amplitude. For photographing the trace it is desirable that all parts of the trace show approximately equal brightness, and in particular that the signal traces appear clearly. This requirement is met by feeding the detection signal into an amplifier with a switch-selectable amplification factor of 10 or 100 and in turn feeding the output of that amplifier into the z-axis input of the oscilloscope to modulate the trace intensity (The second amplifier is required to provide the high-level input required for the z axis). The intensity controls are then adjusted to result in a trace of approximately constant brightness as shown, for example, in figure 6. This adjustment is made with the shaker operating at a fixed frequency. Slight adjustments to the intensity settings may be required at the beginning of each specimen test, depending on the device type and the particles present.

A further refinement was required with the system A amplifier when particles at the high end of the mass range were detected. The signals resulting from impacts of the relatively more massive particles at times saturated the amplifier, as evidenced by peak clipping in the output signal. To eliminate this overloading of the amplifier, a simple voltage divider was used for specimen devices known to have particles with diameters of 0.102 mm or larger; the ratio of the divider was adjusted to be 1:10 at 150 kHz; at both 100 and 200 kHz the ratio was measured and found to be within 2% of the 1:10 value. It is recognized that, although this solution is useful for this laboratory evaluation in which the size of the particle to be detected is known beforehand, other approaches are required for PIND tests of production devices.

The NBS shaker with its associated control and drive equipment used in this work has a frequency range from 5 to 5000 Hz, an upper acceleration limit of ±67 g_n, and a double-amplitude limit of 12.7 mm. This shaker can be programmed to sweep within the specified frequency range from any pre-set frequency to any other pre-set frequency, with acceleration, velocity, or displacement held constant. The sweep period is adjustable from 0.1 to 999 min; up to 99 sweeps may be programmed.

The oscilloscope used in all three test configurations has a frequency response greater than 500 kHz and an input voltage deflection sensitivity of 20 mV per screen division, or better.

2.1.2 Procedures - The general procedure used for each trial of N specimen devices was as follows:

(1) Using customary laboratory procedures, calibrate the oscilloscope vertical deflection amplifier with the control set to 20 mV/ div; the sweep rate to 2 ms/div; and the trigger selection switch to EXTERNAL (trigger signal from shaker drive).

(2) If the laboratory shaker is to be used, calibrate the shaker control system and the accelerometer built into the shaker armature, in accordance with customary laboratory procedures, by means of a precision servo accelerometer and associated amplifier and display.

(3) If the system A shaker is to be used, calibrate its acceleration level control by means of a previously calibrated accelerometer and associated amplifier and display, in accordance with customary laboratory procedures. Mount the accelerometer on the shaker armature next to a TO-5 specimen device centered on the armature; repeat the calibration with a TO-3 specimen.

Note: The purpose of this step is to calibrate the acceleration level control when the shaker armature is loaded by specimen devices of two different masses. For this purpose, the masses of TO-5, TO-18, ceramic dual in-line, and flatpack packaged devices were taken to be equivalent.

(4) If the system B detector module is to be used, calibrate the threshold level monitor by applying a 30-mV peak-to-peak sine-wave signal to the monitor input; adjust the controls so that the indicator light is just triggered ON by this test signal. Set the frequency of the test signal to be that at which the detector module gain is greatest; the nominal value is 155 kHz.

(5) If the threshold level detector is to be used with system A components, attach the drive transducer of the Sensitivity Test Unit face-to-face to the ultrasonic detection transducer with the couplant to be used in the trial. Repeatedly apply a stimulus pulse to the detection transducer by actuating the Sensitivity Test Unit and adjust the threshold level detector to trigger approximately 4 times for every five pulses.

Note: The design of the Sensitivity Test Unit is such that not all stimulus pulses will have the same amplitude.

(6) Assemble the apparatus in the desired test configuration.

(7) If system A components are used, adjust the audio amplifier for maximum audible signal.

If system B components are used, adjust the audio amplifier gain controls so that impacts from a specimen device with a 0.025-mm-diameter aluminum (least massive seed particle) can be detected clearly. Do not readjust the monitor controls.

(8) Energize the system, including the shaker operating at a fixed frequency. Monitor system performance for 5 min. If any detection means show that a signal has been received corresponding to a particle impact, check the system for sources of electrical and mechanical noise. Do not proceed until the requirement for a no-indication period is satisfied. Record the electrical noise level as observed on the oscilloscope. De-energize the shaker.

Note: External sources of mechanical noise may cause problems.

Note: The signal cable from the ultrasonic detection transducer may generate electrical noise when flexed. Dress the cable with care. Apply restraints with caution, but make sure that the cable does not see resonances at the test excitation frequency or over the test frequency range.

(9) Clean the mounting surfaces of the ultrasonic detection transducer and the pre-shock apparatus C with an acetone-soaked swab.

(10) Select a specimen device and clean its mounting surface with an acetone soaked swab.

(11) Apply cut strips of couplant E tape to the mounting surfaces of the pre-shock apparatus and the ultrasonic detection transducer.

(12) Mount the specimen to the pre-shock apparatus hammer head. If the specimen is a TO-3 device, apply a thin strip of couplant E tape over the device and onto the hammer head on both sides of the device.

Note: TO-3 devices have rounded mounting surfaces (tops) and couplant E tape at the mounting surface does not provide sufficient restraint when pre- and co-shock accelerations are applied.

(13) Actuate the apparatus to apply pre-shock.

(14) Remove the specimen from the pre-shock apparatus and immediately mount it on the ultrasonic detection transducer. If the specimen is a TO-3 device, apply a thin strip of couplant E tape over the device and onto the transducer on both sides of the device. Inspect the mounted specimen for leads that touch. Separate the leads so that they will not strike each other when the device is vibrated. Inspect the mounted specimen for the presence of foreign material; remove such material. Inspect the mounted specimen for the presence of damaged leads. If it appears that one part of a lead might move with respect to another when the device is vibrated, cut the broken part off or reject the device.

(15) Energize the shaker at the intended acceleration level and frequency (for frequency sweep, at the intended initial frequency). Monitor all detection means used as soon as any power is supplied to the shaker.

(16) If no particle impacts are detected within from 5 to 10 s of shaker turn-on, apply co-shock acceleration to the specimen by the means selected for the trial. Monitor with care all detection means used. If a particle impact is detected by any one of the means used, record the specimen as being seeded in the given trial.

(17) If no particle impacts are detected within from 3 to 5 s of the first co-shock, apply a second co-shock to the specimen. Continue to monitor with care all detection means used. If a particle impact is detected by any one of the means used, record the specimen as being seeded in the given trial.

(18) If no particle impacts are detected within from 3 to 5 s of the second co-shock, apply a third co-shock to the specimen. Continue to monitor with care all detection means used. If a particle impact is detected by any one of the means used, record the specimen as being seeded in the given trial.

(19) If no particle impacts are detected within from 3 to 5 s of the third co-shock, record the specimen as being particle-free in the given trial.

(20) Remove the specimen.

(21) Repeat steps 10 through 20 for 17 specimens.

(22) At least, as frequently as every 18 specimens, clean the mounting surfaces of the pre-shock apparatus and the ultrasonic detection transducer; apply new couplant.

(23) Repeat steps 10 through 20 eighteen times.

(24) After 36 specimens, repeat step 8. Continue only if the requirement for the 5-min no-indication period is satisfied.

(25) Continue with steps 10 through 20 and, as appropriate, steps 21 through 24 until all N specimens are tested.

The data sheet used in connection with this procedure is shown in figure 7. As shown, the sheet includes space for indicating the magnitude of the detection signal as observed on the oscilloscope screen or as heard from the loudspeaker. (The notation is intended to convey the following: A signal is recorded as being very small (VS), small (S), medium (M), or large (L) in amplitude or duration. The VS notation is used to indicate a signal which may represent a false detection instead of a particle; S indicates a signal about which there is little question that the signal represents a particle; there is no question about signals designated M and L.) The noise level is that recorded in step 8. The laboratory ambient temperature is measured at the start of a trial. The data sheet also provides a code for indicating when a detection signal was received in the test sequence.

2.1.3 Microelectronic Device Specimens - Three groups of microelectronic specimens were used in the work. Each group consisted of intentionally seeded devices, with a small number of unseeded devices as controls.

Particles used to seed specimen devices were chosen to be representative of particles likely to be found in devices as a result of production and processing steps and ranged in mass from 0.1 to 21.1 µg. Particles of smaller mass were considered to be only marginally detectable and, if in the form of a lump instead of a sheet or needle, much less likely to cause short-circuit failure. The majority of seed particles were spheres of gold, aluminum, lead, or silicon-aluminum, ranging in diameter from 0.025 to 0.13 mm; a limited number were gold or aluminum flakes approximately 0.3 x 0.05 mm in size; and 12 were short lengths of fine gold wire.

The 25 specimens in Group I were immediately available at the start of the work and, although they are empty packages with neither dice nor leads, were used until more representative specimens became available. [Two of the Group I specimens are unseeded.]

The 252 specimens in Group II were fabricated for the work by an outside supplier using dice that had shown on electrical fault; in other respects (except, of course, the inclusion of a seed particle) the completed Group II specimens are not distinguishable from production devices. In particular, the Group II specimens included all connecting leads. Primarily because of long procurement lead times, the Group II specimens became available only in the fifth month of work, substantially later than planned.

The 165 specimens in Group III are hybrid packages that were produced for NASA Marshall Space Flight Center in connection with another program [6]. These specimens have ceramic substrates (6.4 mm in thickness and sized just to fit in the package) and external leads. No internal leads or metallization are present. Group III specimens became available in the last month of work.

Table 2 gives for Group I specimens: device type, number of specimens, seed material and diameter (all Group I seeds are spherical), and calculated mass. (The diameter is known to on the order of 10 µm (0.0004 in.); the uncertainty in calculated mass values ranges from +120%, -66% for nominal 0.025-mm lead to +16%, -14% for nominal 0.150-mm lead; other values are +36%, -27% for 0.076-mm lead, +52%, -34% for 0.051-mm gold, and +24%, -21% for 0.100-mm gold.) The two unseeded specimens are so identified. Similar information for the Group II and Group III specimens is given in tables 3 and 4, respectively.

The Group II specimens were prepared both for the NBS work and for intended later use as subjects of an interlaboratory evaluation of PIND methods. Because of questions about the characterization of these specimens that are raised later it is of interest to note the supplier's description[3] of the fabrication procedures used:

"1 Headers and cans or lids were purchased.

"2 Headers and cans were cleaned by the Freon spray process used for our high reliability assembly. Freon spray was conducted in a clean room and the cleaned devices were sealed in special contaminant-free plastic bags.

"3 The particles were purchased or supplied by NBS.

"4 The particle was placed inside the can or cavity of the device and then the particle was optically measured.

"5 The can and header were inspected at 50X magnification for extraneous matter before and after insertion of the particle.

"6 The device was then sealed."

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[3]In a letter from the supplier to J. S. Hilten, in response to questions raised by the authors.

The supplier has further indicated that 20 seeded devices of each type and seed were prepared for every three supplied to the NBS as specimens. The specimens were selected on the basis that in each of four consecutive PIND trials, a selected specimen showed a positive indication of the presence of a particle, with the exception of specimens seeded with particles 0.025 mm (0.001 in) in diameter.[4] For specimens with this size of seed, the situation depends on the particle material, as follows: The PIND test method and apparatus used by the supplier were not capable of detecting aluminum particles 0.025 mm in diameter. Gold particles of this size were detected in all devices except the ceramic dual in-line packages. Lead particles 0.025 mm in diameter were detected in the TO-18 packages and in one of the flat-pack ceramic packages. The supplier noted that the lead particles that were not detected were probably immobilized by electrostatic charge and referred to numerous microscope observations of the behavior of a lead particle of this size in devices with glass packages and in open packages (incidentally, the supplier indicated that these locked up small lead particles require the application of very high acceleration levels -- up to 9000 g_n -- to become free). Unseeded devices were also subjected to four consecutive PIND trials; those supplied as specimens not only showed no detections in these trials but also no evidence of loose material in radiographic examination.

The supplier described the conduct of his PIND trials as follows:

"1 Three pre-mount shocks of 400-600 G's.

"2 Immediately (1-2 seconds) mount device on transducer.

"3 Vibrate and observe for 2 seconds.

"4 Co shock 1/2 second at approximately 200 G's.

"5 Vibrate and observe for 3 seconds."

The method for applying pre-shock excitation was to tap the specimens on a table top; co-shock excitation was applied with a No. 10 copper rod, in accordance with Method 2020.

2.1.4 PIND Trials on Group II Specimens - Following receipt of the Group II specimens from the supplier, major comparative trials of PIND methods and apparatus could be carried out, and accordingly the seven trials summarized in table 5 were run. Trial 1 was intended to provide a baseline for comparison with the results from subsequent trials. The results from this trial (table 5, last two columns) were considered unsatisfactory in that (1) the overall percentage of seeded specimens for which seeds were detected is much lower than anticipated on the basis of reports in the literature and NBS experience with Group I specimens and (2) the number of false detections in unseeded specimens is unexpectedly large. Trial 2 was conducted in the same manner as Trial 1, except that the test frequency was determined for each package type from data provided in Test Method 2020. To use the data, it is necessary to know the "average internal package height." Since this dimension is not defined in the Test Method, it was taken to be the distance from the top of the

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[4] The tabular data include particle diameter or sizes in both SI and U.S. customary units. For simplicity, a conversion to inches will be given the first time a new SI dimension appears and not repeated.

microcircuit chip to the inside surface of the package lid. The test frequencies used were 43 Hz for TO-5 cans, 49 Hz for TO-3 cans, 61 Hz for TO-18 cans, 81 Hz for ceramic dual in-line packages (CDIP), and 96 Hz for both metal- and ceramic-lid flatpacks. The results of this trial were in general agreement with those of trial 1.

At this point it was necessary to decide if the trials should be continued without an understanding of the low detection score on the one hand and the high false detection level on the other or if the trials should be interrupted and the initial characterization by the supplier checked. With respect to specimen characterization, four probable situations were recognized:

(1) the specimens were correctly characterized by the supplier, some event which resulted in new specimen states took place subsequent to that characterization and prior to the first NBS trial, and the NBS trials adequately characterized the new states;

(2) the specimens were correctly characterized by the supplier, the first NBS trial resulted in new specimen states as these states were being characterized, there was no further change in states, and NBS trials adequately characterized the new states:

(3) the specimens were correctly characterized by the supplier, no change in specimen states took place, and the NBS trials inadequately characterized the states; and

(4) the specimens were not correctly characterized by the supplier and, regardless of whether the initial specimen states were changed, the NBS trials adequately characterized the states as they were at the time of trial.

Other series of events, including combinations of causes and changes induced by the trials themselves, are philosophically possible, but were not thought adequate in terms of explaining the major discrepancy. Situation (4) did not seem likely for several reasons. The supplier is a major manufacturer of microelectronic devices and has PIND-tested many thousands of devices; there was no reason to assume that his procedures or apparatus should be at fault. While it is true that immediate consecutive PIND testing of a series of devices has in a few cases shown a tendency to promote particle lock-up, there is no evidence for such a large effect as the present data require. A series of labeling errors is of course possible, but suggests an improbably high degree of carelessness in light of the intended use of the specimens. Situation (3) also was judged not likely in the light of [NBS] experience with the Group I specimens and especially in the light of results of a "control" trial of these specimens interpolated into Trial I when the results indicated possible problems. Seed particles in 21 out of 23 seeded specimens were detected (the two not detected have never been detected in an NBS trial), one specimen which was supplied as unseeded but which has generally shown a positive reaction was again characterized as containing a free particle, and no particle was detected in the remaining unseeded specimen. Work with the Group I specimens and other tasks had provided considerable experience with false detection problems; a thorough re-check of the apparatus showed no evidence of any source of mechanical or electrical noise.

Situations (1) and (2) are similar in that it is not possible to distinguish between them on the basis of the new specimen states. Plausible explanations for both situations exist. Rough handling during shipping or delivery could result in (1); no positive evidence is available on this point. Comparison of the test procedures used by the supplier and by NBS shows that the pre-test shock excitation provided the specimen at NBS was much greater than that indicated by the supplier. The Test Method specifies that the pre-test shock be 500 to 1500 g_n; it further specifies the use of commercial apparatus C or equivalent. Later work, described in 3.3.1, shows that with a 10-g mass in the specimen position, the single apparatus C tested generated a shock acceleration of about 2300 g_n.[5] This was the same apparatus used to apply pre-test shock to all the Group II and Group III specimens before they were characterized at NBS. While it is attractive to regard the high pre-test shock as responsible for "permanently" immobilizing some particles while "generating" others (or breaking leads), the caution should be given that manual tapping of specimens on a table with no apparatus is not likely to yield consistent results in terms of peak acceleration imparted; long-term experience with applying accelerometers to a wide variety of measurement situations suggests that the variation in shock could be very much greater than that indicated by the supplier.

The selection of situation (1) or (2) as the likely true situation suggested that the trials should be continued without interruption as there was no reason to expect any further changes in specimen states and no way to restore existing states to initial ones. The suggestion was made that, following the NBS trials, the specimens be returned to the supplier for re-characterization; this was done, with results reported in 3.1. Further discussion of results is left to that section.

Trial 3 was a companion to Trial 2 with an acceleration level of ±20 g_n, twice that of Trial 2. These trials taken together were intended to compare results at the two acceleration levels specified in the Test Method.

Trial 4 was an attempt to determine the effect on detection performance of a downward frequency sweep from 250 to 40 Hz used instead of a single fixed frequency; in other respects the conditions were the same as those of Trial 2. The period of sweep was 2 min; co-shock excitation was applied every 10 Hz. The innovation of using a frequency sweep was suggested to match test frequency with (1) the range of internal heights expected as a result of manufacturing tolerances and (2) other internal package dimensions. The frequency range used corresponds to internal heights (dimensions) from 0.13 to 4.6 mm (0.005 to 0.180 in) at ±10 g_n and corresponds to the frequency capability specified for the shaker in the Test Method. The suggestion was also made that a frequency sweep might dislodge particles in configurations such as flakes, chips, and rods with largest dimensions on the order of a few tenths of a millimeter. (The logarithm of the frequency is inversely proportional to the logarithm of the dimension; for a dimension of 0.025 mm, the corresponding frequency is between 500 and 600 Hz.)

Trials 1 through 4 were all conducted with test configuration 2, using system B components. Trial 5 was carried out with test configuration 1, using system A components with an acceleration level of ±10 g_n and co-shock excitation

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[5]See 3.3.1 for a discussion of the uncertainties of this measurement. With only the accelerometer in place (mass 0.2 g), the shock acceleration was about 2700 g_n.

applied manually with a copper rod 2.6 mm in diameter (AWG No. 10), as specified in the Test Method. The intent of this trial was to compare the performance of System A with that of System B.

Trial 6 was a repeat of Trial 1, with the purpose of comparing the results obtained using the same apparatus and techniques, and by the same operator, but separated by an interval of time, in this case, by 90 days.

Trial 7 was carried out as an effort to characterize the specimens in a manner identical insofar as possible to that used by the supplier in carrying out the original selection of specimens.

2.1.5 PIND Trial on Group III Specimens - Toward the end of the work, the 165 hybrid microelectronic devices constituting Group III became available and were used as PIND test specimens at the request of the sponsor. A single trial with test configuration 2 was carried out; the acceleration level used was ±10 g_n, and the exciting frequency was 60 Hz. Pre-test shock was applied to all Group III specimens by means of apparatus C. In addition, fifteen of the Group III specimens were PIND tested in a preliminary trial in connection with attempts to verify detection system performance in connection with trials on the Group II specimens. Test configuration 2 was used with pre-test shock applied by means of apparatus C.

2.2 Characterization of Shock Accelerations Imparted by Commercial Apparatus

2.2.1 Pre-Test Shock Apparatus C - A commercial piezoelectric accelerometer (with a mass of 0.2 g, considerably less than that of a representative TO-5 specimen, which has a mass of 1 g) was mounted in the test specimen position on the top of the hammer head of Apparatus C, and the shock levels imparted by the apparatus to the accelerometer measured in a series of tests as follows:

(1) The accelerometer was mounted in a centered postion using couplant F;[6] the acceleration shock level was measured for five consecutive actuations of the apparatus to establish measurement repeatability. In five additional runs, the accelerometer was removed and remounted and the shock level measured; the data from these tests are intended to provide a measure of the variation introduced by remounting.

(2) A similar set of tests was repeated for couplants D and E. Couplants D and E are tapes with adhesives on both sides; fresh tape was used for each remounting.[7]

(3) The accelerometer was mounted in a centered position using couplant F; the acceleration shock level was measured with only the accelerometer in place (a repeat of one of the measurements made in the previous series) and then with masses of 1, 2, 5, and 10 g loading the hammer

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[6] Couplant F is described by the manufacturer as a water-soluble paste capable of transmitting ultrasonic vibrations.

[7] Couplant D is a semi-transparent material about 0.13 (0.005 in) thick; couplant E is a white material about 0.36 mm (0.014 in) thick.

head. These tests were carried out with three couplants for a total of 15 runs.

(4) The shock level was measured at four sites, one in each quadrant of the top of the hammer head, to simulate substantial off-center attachment of a specimen. A fifth measurement was made with the accelerometer centered. These tests were also carried out with all three couplants for a total of 15 runs.

The shock levels were measured from photographs of the oscilloscope traces; these photographs also serve as waveshape records.

2.2.2 Co-Shock Apparatus, System B - The same accelerometer as described in 2.2.1 was mounted in the test specimen position on the face of the System B ultrasonic transducer (which is integral with the System B co-shock apparatus), and the shock levels imparted by the apparatus to the accelerometer measured in a series of tests as described in 2.2.1. (In 3 and 4 substitute "ultrasonic transducer" for "hammer head." The means of measurement of shock levels and of recording waveshape were the same as those of 2.2.1.)

2.3 Other Tests

2.3.1 Preliminary Tests with Group I Specimens - A number of developmental tests were carried out using Group I specimens and the generation of amplitude-frequency plots as described in 2.1.1 as an evaluative method. These experiments are summarized in table 6 and are concerned with the effect of couplant type, seed particle mass, and acceleration level on detection signal level. Also investigated were the effects of acceleration level and frequency on the tendency of the seed particles to lock up. In this investigation, the time from application of co-shock until lock up was recorded, or the run terminated after 20 s (if no lock up occurred).

The preliminary tests also provided information on the repeatability of the amplitude-frequency technique and information on the effect of package type on the frequency response of the detection signal for a given seed particle.

2.3.2 Comparison of Detection Performance of Four Ultrasonic Transducers - The detection performance of four piezoelectric crystal ultrasonic transducers manufactured by the supplier of System A components was compared in an experiment with PIND tests, using the amplitude-frequency plot method described in 2.1.1. Three of the transducers (H, I, and J) are the same model while the fourth (G) is a variation on the basic model characterized by the manufacturer as having "high sensitivity." The values of sensitivity in dB (referred to 1V) per 0.1 Pa as determined by the calibration chart supplied with each instrument are -76, -79, -78, and -79 for transducers G, H, I, and J, respectively. Test configuration 3 was used, the acceleration level was ±10 g_n, and the 2-min frequency sweep was from 25 to 250 Hz. Specimens were mounted with couplant D.

Amplitude-frequency plots were recorded for runs with each of the four transducers in turn, the specimen being a Group I package seeded with a gold ball 0.051 mm (0.002 in) in diameter. In a second test, plots were recorded for runs with transducers G and H, the specimen being a Group I TO-18 package seeded with a lead ball 0.076 mm (0.003 in) in diameter.

2.3.3 Pneumatic Co-Shock Experiment - Consideration of mechanical means to free immobilized particles led to the suggestion that co-shock acceleration be applied along more than one direction. Further thought along these lines resulted in a proposal to apply co-shock to the specimen with a pressure pulse. As equipment, in the form of a quick-opening (1 ms) solenoid valve and an air tank, was available to generate the required pneumatic pulse, a small-scale experiment was carried out in which the system A ultrasonic transducer was mounted on the inside bottom of a small cylindrical aluminum pressure vessel with removable lid, the vessel in turn being mounted on the NBS shaker armature. Couplant E was used to attach the specimen to the transducer. With the lid in place, three pneumatic co-shocks were applied with the shaker operating at ±10 g_n at 60 Hz. Apart from the pressure vessel, the arrangement was that of test configuration 1. A single run was carried out on 30 Group II specimens.

3. RESULTS AND CONCLUSIONS

3.1 PIND Tests on Group II Specimens

A summary of the detection scores in terms of the percentage of specimens containing seed particles that were detected of the total number of seeded specimens is included in table 5 for the seven NBS trials. As noted in the narrative of 2.1.4, the results shown in table 5 for the first two trials led to a review of the situation, which resulted in a decision to continue the trials as planned. Examination of the results of trials 3 through 7 shows general agreement with the earlier trials, and detection scores are disturbingly low with false detection scores that are disturbingly high. Again referring to 2.1.4, the analysis of the most likely true state of affairs and subsequent contact and discussion with the suppliers of the Group II specimens resulted in an offer by the supplier to re-examine the Group II specimens with the same PIND procedures used initially. The supplier actually conducted these trials, identified as trials 8, 9, and 10 in table 7. The general agreement of the detection results of these trials with the seven NBS trials strongly suggests that, for whatever reason, the initial characterization is not valid. Table 8 shows the detection scores by seed particle for the ten trials; table 9 is a "corrected" table of detection scores assuming that a single positive detection of a seed particle in a specimen in any of the trials renders that specimen as seeded. NBS overall, supplier overall, and combined overall detection scores for each type of particle are also given in both tables. Note that table 9 does not cover detections in specimens that were initially characterized as unseeded and also that the calculated detection scores reflect only specimens for which there was at least one positive detection in the ten trials. The degree of agreement for the modified characterization is demonstrated in Table 10, which shows the correlation between the seven NBS and the three "post-NBS" trials conducted by the supplier, together with average values for each size and composition of seed. Trials on specimens initially characterized as unseeded are again not covered. To interpret the percentages given in the table, consider the meaning of "89" given for an aluminum sphere 0.076 mm in diameter in trial 3. This number indicates that in trial 3, 89 percent of the tests carried out on specimens originally supposed to contain the seed in question showed agreement with the modified characterization. The figures are thus not detection scores as given elsewhere, but agreement scores.

Some general conclusions may be drawn from the results (these conclusions and results refer only to the NBS trials unless otherwise stated), the chief one being that detection of a seeded particle in a specimen package is to a large extent a function of the given package type. The overall uncorrected detection scores by package type for the seven NBS trials are as follows:

TO-18	80 percent
TO-5	67 percent
TO-3	55 percent
flatpack with metal lid	25 percent
flatpack with ceramic lid	24 percent
ceramic dual in-line	21 percent

There may be significance to the fact that the overall detection score for the seven trials is 67 percent for specimens with metal packages and 23 percent for specimens with ceramic or part-ceramic packages. Detailed data are given in Appendix I.

The largest detection-score difference between replicate trials is 5 percent. However, there are only two sets of replicate trials, one set for system A components in test configuration 1 (trials 5 and 7) and one set for system B components in test configuration 2 (trials 1 and 6). On this limited basis, it is assumed that a difference on the order of 10 percent is probably significant, while smaller differences may have significance but require further trial.

A problem that should be noted in connection with multiple trials on a single set of specimens is that it is possible for more and more particles to become immobilized with each succeeding trial. For this consideration, "immobolized" is taken to mean permanently immobilized for the purposes of the PIND trials. The results of all ten trials may suggest that a depletion of free particles is occurring, but more trials would be required to establish a significant trend.

The above cautions for interpretation apply to the following results and conclusions (all detection scores are uncorrected as given):

(1) The use of system B components in test configuration 2 provided higher average detection scores (of approximately 45 percent for trials 1 and 6) than the use of system A components in test configuration 1 (score of approximately 39 percent for trials 5 and 7), with all trials conducted at ±10 g_n and 60 Hz.

(2) The use of the higher acceleration level of ±20 g_n in trial 3 resulted in an improved overall detection score (55 percent as compared with 50 percent for ±10 g_n, trial 2). There is evidence that for certain package types, the higher level of acceleration is desirable while the reverse is true for other package types. For example, examination of the tabular results for trials 2 and 3 in Appendix I shows for the higher acceleration level an increase in the detection scores for TO-3 and TO-5 specimens of 12 percent and a decrease in the scores for TO-18 specimens of 3 percent and in the scores for ceramic-lidded flatpack specimens of 6 percent.

(3) The use of test frequencies based on the data provided in the Test Method did not result in significantly higher detection scores than the use of the single fixed frequency of 60 Hz. The largest increase for seeded specimens was 6 percent for flatpacks with ceramic lids (trials 1 and 2).

(4) The use of a frequency sweep from 250 to 40 Hz for each test (trial 4) showed significantly lower detection scores compared to those of trial 3; for all package types but one there was a drop ranging from 3 to 18 percent.

(5) In general, larger masses are more readily detected than smaller. The ratio of the largest mass (10.6 μg for a gold sphere 0.10 mm in diameter) to the smallest (0.023 μg for an aluminum sphere 0.025 mm in diameter) of any of the spherical seed particles used in the Group II specimens is 460: 1 (the mass of neither the gold nor the aluminum flakes is known). Examination of the data given in the "totals" row in the tables of Appendix I shows that in only one instance -- in trial 2 -- was the actual number of positive detections lower compared to the results obtained for a seed particle of the same material but greater mass.

(6) Thirty-three percent (66 specimens) of the 198 seeded specimens tested free of particles for all seven NBS trials. Fifty-six percent (30 specimens) of the 54 "unseeded" specimens tested free of particles for all seven NBS trials. Eleven percent (6 specimens) of the 54 "unseeded specimens showed positive detections for all seven NBS trials. The validity of the specimen characterization on which these results are based has been discussed in the first part of this section.

3.2 PIND Trial on Group III Specimens

The results of the trial described in 2.1.5 are summarized in table 11. Note that the false detection rate (assuming that no free particles were present in the unseeded specimens) is high. These limited results suggest strong dependence on the package configuration, although the applicability of this conclusion to actual devices is tempered by the fact that the Group III specimens do not contain internal leads, and by the low detection scores. It should be kept in mind, however, that a 0.17-μg gold sphere is only 0.025 mm in diameter.

The short trial of 15 seeded Group III specimens (one of each device represented by these specimens) resulted in three detections, all achieved before co-shock was applied. Two of these were in 25 x 25 mm ceramic flatpacks, and one in a TO-8 can with a gold wire seed. These results are not statistically significant, but are consistent with the trial summarized in Table 11.

3.3 Characterization of Shock Accelerations Imparted by Commercial Apparatus

3.3.1 Pre-Test Shock Apparatus C - The selection of the accelerometer used in the measurements of the acceleration imparted by the pre-test shock apparatus is a compromise between the conflicting requirements of low mass, adequate acceleration range, and high-frequency response. Accordingly, the measurements described in 2.2.1 are subject to the following corrections and uncertainies:

(1) The accelerometer used has a natural frequency of 54 kHz, according to its manufacturer. Experience with measurements using single-degree-of-freedom accelerometers shows that accelerometer output is flat to 20 percent of the instrument natural frequency; in this case, to 10.8 kHz ("flat" is taken to mean that the accelerometer output does not vary by more than 5 percent from the mean value over the useful range). For frequencies above 10.8 kHz, it is necessary to apply a correction factor. The waveshape of the shock acceleration imparted by apparatus C approximates a half-sine curve with a period of 50 μs (frequency of 20 kHz), as shown in figure 6. Assuming a nominal damping ratio of 0.01 of critical damping (the transition between underdamped and overdamped [7]), a correction of approximately -16 percent is required to the measured peak acceleration value. This correction is consonant with the manufacturer's estimate that the frequency response is within ±7 percent of the 100-Hz value within the range from 5 to 10,000 Hz.

(2) The manufacturer states that the sensitivity of the accelerometer increases about one percent for every 250 g_n over the range from 0 to 4000 g_n (for example, a reading of 4000 g_n requires a correction of about -500 g_n).

(3) The manufacturer estimates the calibration error to be within ±2.5 percent.

(4) The manufacturer states that the shock-induced zero shift at nominal room temperature is less than ±6 percent of the reading over the range from 1000 to 4000 g_n. The initial peak reading is not affected by this factor.

(5) Equipment required to check the accelerometer calibration at accelerations above ±60 g_n is not available. The accelerometer was calibrated at ±20, ±40, and ±60 g_n over a frequency range from 50 to 5000 Hz; the results of this calibration were in agreement with the manufacturer's data, taking into account the uncertainties discussed in this section.

(6) Replicate measurements of the acceleration levels imparted by apparatus C result in deviations of no greater than 7 percent of the calculated mean values.

(7) The overall uncertainty in the pre-shock measurements is estimated to be ±12 percent, based on the above uncertainties together with long-term experience with the accelerometer and associated instrumentation in question.

(8) The results given in this section have been corrected by approximately -32 percent in accordance with (1) and (2).

The following results were recorded:

(1) The mean peak shock acceleration produced by apparatus C, loaded with only the mass of the accelerometer and couplant tape, is 2700 g_n. The waveshape, shown in the upper photograph of figure 8, approximates a half-sine curve; the duration of the first "pulse" is approximately 50 μs.

(2) Additional loading of apparatus C by a 10-g mass lowers the mean peak acceleration to approximately 2300 g_n, 85 percent of the unloaded value given in (1).

(3) The effects of remounting, of the use of any of the three couplants tested, and of off-center mounting of the accelerometer makes no detectable difference in the mean acceleration values. Put another way, deviations do not exceed 7 percent from the mean and are thus well within the estimated uncertainty of the measurement.

3.3.2 Co-Shock Apparatus, System B - The measurements described in 2.2.2 are subject to the same corrections and uncertainties given in 3.3.1, as the same accelerometer was used. The selection was again dictated by the need to compromise between the conflicting requirements of low mass, adequate acceleration range, and high-frequency response. The correction factor is -13 percent (-7 percent, frequency response; -6 percent, sensitivity) for the mean peak acceleration levels measured; the overall estimated uncertainty is the same as that given in 3.3.1.

The following results were recorded:

(1) The mean peak acceleration produced by the co-shock apparatus, system B, loaded with only the mass of the accelerometer and couplant tape, is 1300 g_n. The waveshape, shown in the lower photograph of figure 8, exhibits a ringing frequency of approximately 14 kHz; decay of signal amplitude to 10 percent of its initial peak value occurs in approximately 1 ms.

(2) Additional loading of the co-shock apparatus, system B, by a 10-g mass lowers the mean peak acceleration to approximately 900 g_n, 70 percent of the value given in (1).

(3) The effects of remounting and of the use of any of the three couplants tested makes no detectable difference in the mean acceleration values. Off-center mounting of the accelerometer reduces the mean peak acceleration to approximately 900 g_n. Replicate measurements show results with deviations from the mean value no greater than 5 percent of that value, well within the estimated uncertainty of the measurement.

3.4 Preliminary Tests with Group I Specimens

A caution that should be kept in mind in connection with interpretation of the results of these tests is the nature of the specimens, described in 2.1.3. Empty packages may not be an adequate representation of complete devices.

The tests are described in 2.3.1 and table 6; results are as follows:

(1) Couplant Tests

For the TO-5 and TO-18 specimens, the use of tape couplant D resulted in the largest output from the transducer-amplifier combination. With couplant E the output was slightly less than that with D; with jelly couplant F, the output was significantly lower than that with D, from 25 to 50 percent lower over the swept frequency range. For the metal flatpack, these results were approximately reversed. Replicate runs with the three specimens repeated the ranking. If the output from the amplifier is a function of the particle impact frequency and of the composite frequency response of the couplant-transducer-amplifier system, the results may be taken as indicating that the frequency response of one or more of the couplants is not flat.

All three couplants are acceptable for PIND testing; for any one set of test conditions, one couplant is likely to attenuate the desired signals the least. Following these tests, tape couplant D was selected for use, as a number of PIND testing facilities are known to be using this type.

Test apparatus: configuration 3 with System A amplification and detection system, NBS shaker, ultrasonic transducer H.

(2) Investigation of Effect of Particle Mass

A preliminary analysis suggested that the output of the transducer-amplifier system would be directly proportional to the mass of the seed particle. The results of a series of amplitude-frequency tests generally confirm this prediction, although the imprecision in the knowledge of the seed particle mass (2.1.2) is large. Four TO-5 specimens seeded with particles as described in table 6 were used for these tests. Nominal seed-particle mass, system output (values given are for the approximate average output recorded at frequencies between 25 and 75 Hz), ratios of masses (with the reference mass 1.3 μg), and ratios of the corresponding outputs of the transducer-amplifier system computed from the amplitude-frequency oscilloscope traces shown in figure 6 (with the reference output 0.65 V) are as follows:

Nominal Particle Mass (μg)	System Output (V)	Ratio of Masses	Ratio of Outputs
1.3	0.65	1.0	1.0
2.6	1.0	2.0	1.5
10.6	4.8	8.2	7.4
21.1	8.8	16.2	13.5

Test apparatus: configuration 3 with system A amplification and detection system, NBS shaker, ultrasonic transducer H.

(3) Investigation of Effect of Shaker Acceleration Level

The amplitude-frequency tests were performed at three acceleration levels on all Group I specimens with the following exceptions: the four specimens seeded with 0.025-mm-diameter particles (it proved to be too difficult to keep these particles moving for the full 2 min required for the frequency sweep); two "seeded" specimens that never showed the presence of free particles; and the two un-seeded specimens. Whenever particle lock-up occurred during a test, the sweep drive was interrupted manually, the camera shutter closed, the specimen co-shocked to free the particle, the shutter re-opened, and the sweep continued.

Figure 6 shows typical oscilloscope traces obtained during these tests. Data reduced from these and other traces indicate that the use of higher accleration levels results in (1) larger outputs from the transducer-amplifier system with the same, or similar, seeded specimens (about twice the output was observed when the same specimen was vibrated at an acceleration of ±20 g_n as compared to ±5 g_n) and (2) wider frequency bands over which substantial output can be obtained from the transducer-amplifier system. For example, consider the results from a specimen with a 0.076-mm-diameter lead seed (the specimen represented by figure 6, g, h, and i. In these photographs, the output levels remain at their higher values until about 50 Hz for an acceleration of ±5 g_n, to about 80 Hz for ±10 g_n, and to about 120 Hz for ±20 g_n.

Test apparatus: configuration 3 with system A amplification and detection system, NBS shaker, ultrasonic transducer H.

(4) Lock-up Behavior Tests

Investigation of the effects of acceleration level and frequency on the lock-up behavior of seeded specimens confirmed earlier observations that for TO-18 type specimens seeded with 0.051-mm-diameter gold particles and 0.076-mm-diameter lead particles, lock-up occurs more readily at the lower frequencies of 20 and 30 Hz than at the higher frequencies of 60 and 100 Hz, and at the higher acceleration levels of ±20 and ±10 g_n than at the lower acceleration levels of ±5 and ±3 g_n. However, for similarly seeded TO-5 and metal flatpack types, no relationship could be inferred between lock-up behavior and acceleration level or frequency (no lock-ups occurred within the 20-s test period throughout all 140 tests). Data are given in table 12.

Test apparatus: configuration 3 with system A amplification and detection system, NBS shaker, ultrasonic transducer H.

(5) Repeatability

Plots of the transducer-amplification system output signal level for amplitude-frequency tests on the same acceleration level conducted at different times throughout the preliminary investigations showed acceptable repeatability in the level over the test frequency range, that is, no variation in level averaged over 10 Hz was larger than about 10 percent. The three sample oscilloscope traces shown in figure 9 demonstrate the typical degree of trace repeatability observed.

Test apparatus: configuration 3 with system A amplification and detection system, NBS shaker, ultrasonic transducer H.

(6) Investigation of Package Signatures in Oscilloscope Traces from Amplitude-Frequency Tests

Comparison of the oscilloscope traces recorded during amplitude-frequency tests of the three Group I package types with nominally identical seed particles shows some characteristic differences in the trace configurations and levels associated with each package type (see figures 6 and 10). For example, with the same test conditions, traces taken of tests on metal flatpacks show the widest (and those for the TO-5s the narrowest) frequency band of enhanced output. Again for the same test conditions, transducer-amplifier system output is highest for TO-18 packages, followed by TO-5s and then by metal flatpacks. These generalizations may tend to explain ratios of detectability scores in some trials, but this type of analysis should be approached with caution. It should be pointed out that at least by visual inspection the similarities between two trace patterns each associated with a different package type may sometimes be greater than the similarities between two trace patterns for the same type.

Test apparatus: configuration 3 with system A amplification and detection system, NBS shaker, ultrasonic transducer H.

3.5 Comparison of Detection Performance of Four Ultrasonic Transducers

This experiment (2.3.2) was carried out primarily to see if use of the high-sensitivity transducer type would result in an increased detection signal amplitude (at least at some frequencies) and hence an improvement in signal-to-noise ratio. It was anticipated that the results would likely be indicative at best, as the frequencies generated by the impact of various particles in various package geometries are not well characterized (and almost certainly vary over a wide range) and the transducer-output-as-a-function-of-frequency characteristics, as supplied by the manufacturer, show very uneven response, with a local sensitivity maximum at 150 kHz. The difference in outputs for the two types at this frequency is on the order of 2 dB; the major difference between the two response curves is that the high-sensitivity instrument does not show rapid drop either side of 150 kHz, but is relatively flat. For the "normal" instrument, the response at 175 kHz is nearly 40 dB down from the 150-kHz value and then rises steeply again to about 10 dB down at 200 kHz. The combined frequency-response characteristics of the transducers with the amplifier are not available and were not determined.

Amplitude-frequency plots from the first test showed no significant variations in the amplitude of the detection signal for any of the four transducers; all signals were well above the noise level so that the presence of a particle was indicated without ambiguity. In the second test, the output signal from the high-sensitivity transducer G was found to have as much as 25% greater amplitude than that from transducer H. The transducers are all said to be designed with a maximum sensitivity at 150 kHz.

No real conclusions can be drawn from these results except that at some, but not all, frequencies transducer G has greater sensitivity than transducer H. However, on a basis of the work overall, it seems likely that increased sensitivity would be useful in the detection of particles with a mass on the order of a few tenths of a microgram or less (always provided that the particles are free), as the detection signal from particles in this mass class may not be much above noise.

It was considered that a thorough investigation of transducer sensitivity as a function of frequency and of the frequencies generated by various particle impacts was beyond the scope of the work.

3.6 Pneumatic Co-Shock Experiment

The results of this experiment (2.3.3) are ambiguous. With a trial of 30 Group II specimens initially characterized as containing detectable particles, detection signals were received in 21 runs. This comparatively high detection score is misleading, as it was found that the air pressure pulse impinging on the ultrasonic detection transducer and connecting cable is capable of generating detection signals with no specimen present. It was judged that considerable work would be required to evaluate this technique adequately and, with the assessment that it would require considerable development to implement as a production test, no further work was carried out.

3.7 General Observations

3.7.1 Electrical Noise - With any high-impedance output, electrical noise produced in connecting cables is a serious concern, The designers of system B incorporate an amplifier in their test fixture specifically to gain the advantage of having a low-impedance connection from fixture to detection circuitry. System A uses a "bare" transducer; consequently, the connecting cable carries a high-impedance signal, and electrical noise may be generated as a result of cable motion or flexing. This problem is exacerbated at (1) lower frequencies, for which the cable motion tends to be large, and (2) higher acceleration levels, for which the inertial forces imposed on the cable tend to be large. A situation in which a cable carries a high-impedance signal therefore requires the use of low-noise cable and careful and constant attention to the manner in which the cable is dressed.

3.7.2 Mechanical Resonance - The component used to couple the ultrasonic detection transducer to the shaker also is intended to isolate the transducer from high-frequency mechanical noise, which may be present in the shaker itself or may have other sources. If the combination of vibration frequency and amplitude used results in a resonance in the coupling element, a spuriously enhanced detection signal amplitude may result. This effect accounts for the enhanced signal amplitude at approximately 200 Hz in parts c, f, i, and l of figure 6. Note that there is little or no evidence of the resonance at lower acceleration levels (parts a, b, d, e, g, h, j, and k of figure 6).

3.7.3 Operator Variability and Fatigue - The bare results of the PIND experiments and trials do not show the presence of an important factor to be considered in the conduct of PIND trials (and, by inference, in production PIND testing), that is, operator variability and fatigue. The NBS experience has been that variability in operator performance (both between different operators and between the same operator at different times) has the potential for affecting results significantly; the results reported for the main PIND trials were achieved with a single operator working within what were judged to be reasonable limits of fatigue. In one test, the use of a second operator was attempted until it became obvious that the results were significantly different from a test run under identical conditions and with the same specimens by the first operator. Observation of the second operator (conducted in a manner so that the second operator was unaware of the observation) showed that, according to the first operator's criteria, a number of devices were being recorded as having no free particle present when in fact there had been an indication of detection. Operator fatigue was also reported to be a problem for a long PIND trial. For example, one operator reported that in the course of a trial extending over a number of hours he became aware that the effort required to make correct decisions, especially for marginal detection signals with pulses appearing fleetingly on the oscilloscope screen, was increasing rapidly and that in order to continue he had to strive to heighten his state of mental alertness.

The NBS experience with operator fatigue can probably be extrapolated to production testing in the form of a caution to managers of personnel conducting routine PIND tests with manual determination of detection, per the Test Method. The caution is simply that the work is demanding in one sense, yet the repetitive nature of it and the nature of the tasks themselves (e.g., looking at an oscilloscope trace) tend to reduce operator alertness and to induce "autopilot" performance. A logical conclusion is that test operators should be chosen and monitored with this warning in mind.

4. RECOMMENDATIONS

4.1 Recommendations Relating to Test Method 2020

These recommendations are based on a limited number of trials and in some cases on trials with packages that did not contain microelectronic device chips.

(1) The most important positive recommendation is that detectability levels be preset and the apparatus configured so that the decision as to whether or not a specimen package contains a particle is made automatically. Presumably, the detection criteria reflected in the apparatus settings would be derived from trials on sample specimens of a given device type or package type.

As noted in 3.7.3, NBS PIND experience supports the finding that operator variability (both between different operators and between the same operator at different times) is a significant factor contributing to inconsistent results in purely manual systems. This observation is particularly pertinent when the test duration is long enough to produce fatigue in the operator. The requirement for adjustable levels of detectability reflects the finding that PIND test results tend to be dependent on the package type for given test conditions, that is, the detectability scores tend to improve when the test conditions match those found by trial to optimize results for the given type. The apparatus should also automatically set and control the acceleration levels applied to the specimen.

Note: Whether more than one acceleration level should be used in a production PIND test will depend on a tradeoff between the improvement in detection performance resulting from multilevel testing, the cost of testing, and the degree of reliability required by the ultimate application.

(2) The NBS measurements show that the acceleration levels imparted to a specimen by the specified pre-test shock apparatus are considerably greater than the 1500 g_n specified in the Test Method (the copy of the Method available to NBS uses the figures "500 to 1500" g_n in 2 (1) and "500 to 1800" g_n in 3.3.1. Since 3.3.1 refers to "2.1", it is assumed that 1500 g_n is the intended upper limit). This situation should be investigated and resolved, as the possibility exists that if PIND test specimens are being subjected to higher shock levels than intended, some otherwise free particles are being either temporarily or permanently immobilized, and damage may occur to device components such as leads.

(3) Before production testing is carried out on a given package type, a quasi-optimized set of test conditions for that type should be determined

by parametric trials on well-characterized specimens. A recommended means for conducting trials is the amplitude-frequency plot method (in which the output of the ultrasonic detection transducer is fed into the vertical amplifier of an oscilloscope for which the horizontal deflection signal is exciter sweep frequency) discussed in 2.1.1.

(4) Consideration should be given to limiting initial acceleration levels to ±10 g_n, or less, at least for some package types. The acceleration imparted to the specimen package by the shaker is one of the test parameters that should be investigated for each new package type. There is evidence in the NBS PIND data that for some package types lowered acceleration levels improve detectability as long as the levels do not fall below some package-dependent threshold, and that for other types detectability is improved, for example, at ±20 g_n compared to that determined at ±10 g_n. When the data for a given package type are either ambiguous or not available, consideration should be given to revising the Method to specity that the test on each device be conducted consecutively first at ±10 g_n, or less, and then at ±20 g_n (see Note under 1).

(5) The Method should specify the maximum permitted impedance of the output from the detection transducer assembly, as cable noise is otherwise a likely problem. The specified impedance should be low compared to the impedance of the transducer crystal itself; a recommended means of achieving this goal is to incorporate suitable impedance-matching circuitry in the transducer assembly.

4.2 Recommendations for Further Work

(1) More trials should be conducted on well-characterized specimen packages to provide a data base for meaningful statistical analysis, particularly with respect to comparing the results of sets of trials in which there is some change from one set to another in test conditions, apparatus, or technique. This recommendation is especially important in the light of the facts that at this writing there are some questions about the characterization of the 252 Group II devices[8] and that neither the Group I packages nor the Group III hybrids without internal leads are entirely representative of production microelectronic devices.

(2) An area that does not seem to be addressed in PIND literature is optimization of the ultrasonic detection transducer and associated circuitry. Present forms of PIND apparatus are designed to operate at a center frequency of 150 kHz. A simplified analysis of particle-impact trajectories and times suggests that higher frequencies may be generated; it is therefore recommended that spectrum analyses of the frequencies present in the signal of a wide-band detection transducer (for example, with a useful frequency response at 1 MHz) be conducted for a representative combination of test conditions and specimen packages.

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[8] It is recommended that in future work, when successive trials on a given group of devices yield anomalous results, the devices be opened for direct inspection.

(3) The NBS work on couplants made use of existing available PIND apparatus, with limited frequency response. It is recommended that further work on couplants be carried out in conjunction with (2) with wide-band, flat-response transducers as both driver and detector, the specimen couplant being sandwiched between the two transducers.

(4) As new apparatus becomes available for PIND testing, it should be evaluated with respect to the requirements of the Method and with respect to the performance of the best apparatus hitherto available. It is specifically recommended that NBS investigate the performance of at least one commercial apparatus that is now available and that does not rely on operator judgment for determination of particle detection.

(5) There is considerable evidence that lock-up problems with small particles of relatively low mass are at least in part the result of electrostatic effects, particularly when the package material is piezoelectric, as may be the case with some ceramic flatpacks. It is recommended that an investigation be carried out on the magnitude and polarity of charge likely to be present during PIND testing of ceramic packages and on means available for neutralizing the charge.

(6) Another area that needs to be studied is the effect of the detailed internal configuration of a device on the statistical probability of particle lock-up, for particles of sizes, materials, and, if possible, configurations most likely to be produced as the device moves through its processing steps. Analyses should be carried out of at least the most likely particle-device interior interactions, including an investigation of the frequencies generated, average impact repetition rates, and the like. An example of this work might be a consideration of the effect of lead-substrate angle on the provision of (wedge-shaped) trapping sites.

It is even possible that PIND considerations should affect microelectronic device design.

5. REFERENCES

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[4] Anon., Loose Particle Detection Investigation Report, internal McDonnell Douglas report prepared by Components, Materials and Processes Branch for the Delta Program and transmitted by memorandum A3-238-AEEEO-M-76-95 (25 Aug. 76) from J. L. Holmgren to D. W. Tutwiler.

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[6] Keister, F. Z., Preparation of Calibrated Test Packages for Particle Impact Noise Detection, HAC Ref. No. D1927 (prepared for NASA George C. Marshall Space Flight Center, under contract NAS 8-30876).

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TABLE 1

COMPONENTS IN COMMERCIAL PIND SYSTEMS

Material in quotation marks is taken from respective manufacturers' literature; measurements on the accelerations imparted are reported in 3.3.

SYSTEM A	
shaker and shaker control system	operating range 1-15 g_n over 14-60 Hz; designed to provide "extremely low mechanical noise background" above 100 kHz
ultrasonic detection transducer	sensitivity at 150 kHz of at least -77.5 ± 2 dB (referred to 1 V) per microbar, as specified in Test Method 2020, in SI units per 0.1 Pa (Note 1)
detector modules	include filter, 60-dB amplifier; amplified signal available for input to oscilloscope; signal to loudspeaker is heterodyned with signal from tunable oscillator to provide "characteristic sound" for free particle
co-shock tool	15-cm length of No. 10 copper wire
SYSTEM B	
combination co-shock fixture and ultrasonic detection transducer with amplifier	energized d-c solenoid contacts transducer on flexible table to provide co-shock; sensitivity at 150 kHz of at least -77.5 ± 2 dB (referred to 1 V) per microbar, as specified in Test Method 2020, in SI units, per 0.1 Pa (note 2); 30-dB amplifier incorporated into fixture
co-shock push-button switch	
detector module with co-shock control	provides three means of monitoring test - amplified detection signal available for input to oscilloscope; high-frequency, high-fidelity speaker for "presenting noise bursts" when particle impacts occur; threshold level monitor with indicating light (once light is lit it stays on until the monitor is reset manually)

Note 1 - The value of sensitivity as determined by the calibration chart supplied with this transducer (H) is -79 dB (referred to lV) per 0.1 Pa (per microbar).

Note 2 - The value of sensitivity as determined by the calibration chart supplied with this transducer (K) is -81 dB (referred to lV) per 0.1 Pa.

TABLE 2

GROUP I SPECIMENS

NUMBER OF SPECIMENS	PACKAGE TYPE	PARTICLE CHARACTERIZATION				
		MATERIAL	SHAPE	NOMINAL DIAMETER (mm)	NOMINAL DIAMETER (in)	CALCULATED NOMINAL MASS (μg)
2	TO-5	Gold	Sphere	0.102	0.004	10.6
2	TO-5	Gold	Sphere	0.051	0.002	1.3
2	TO-5	Lead	Sphere	0.152	0.006	21.1
2	TO-5	Lead	Sphere	0.076	0.003	2.6
2	TO-5	Lead	Sphere	0.025	0.001	.1
1	TO-5	Unseeded				
2	TO-18	Gold	Sphere	0.102	0.004	10.6
2	TO-18	Gold	Sphere	0.051	0.002	1.3
2	TO-18	Lead	Sphere	0.152	0.006	21.1
2	TO-18	Lead	Sphere	0.076	0.003	2.6
2	TO-18	Lead	Sphere	0.025	0.001	.1
1	TO-18	Unseeded				
1	[a] Flatpack	Gold	Sphere	0.051	0.002	1.3
1	Flatpack	Gold	Sphere	0.102	0.004	10.6
1	Flatpack	Lead	Sphere	0.076	0.003	2.6

[a] with metal lid, 6.4 x 3.3 mm (0.25 x 0.13 in), 14 lead

TABLE 3

GROUP II SPECIMENS

NUMBER OF SPECIMENS	PACKAGE TYPE	PARTICLE CHARACTERIZATION				
		MATERIAL	SHAPE	NOMINAL DIAMETER (mm)	NOMINAL DIAMETER (in)	CALCULATED NOMINAL MASS (μg)
3	TO-3	Gold	Sphere	0.102	0.004	10.6
3	TO-5	Gold	Sphere	0.102	0.004	10.6
3	TO-10	Gold	Sphere	0.102	0.004	10.6
3	[a]FPML	Gold	Sphere	0.102	0.004	10.6
3	[b]FPCL	Gold	Sphere	0.102	0.004	10.6
3	[c]CDIP	Gold	Sphere	0.102	0.004	10.6
3	TO-3	Gold	Sphere	0.051	0.002	1.3
3	TO-5	Gold	Sphere	0.051	0.002	1.3
3	TO-18	Gold	Sphere	0.051	0.002	1.3
3	FPML	Gold	Sphere	0.051	0.002	1.3
3	FPCL	Gold	Sphere	0.051	0.002	1.3
3	CDIP	Gold	Sphere	0.051	0.002	1.3
3	TO-3	Gold	Sphere	0.025	0.001	0.17
3	TO-5	Gold	Sphere	0.025	0.001	0.17
3	TO-18	Gold	Sphere	0.025	0.001	0.17
3	FPML	Gold	Sphere	0.025	0.001	0.17
3	FPCL	Gold	Sphere	0.025	0.001	0.17
3	CDIP	Gold	Sphere	0.025	0.001	0.17
3	TO-3	Gold	Flake	0.051 x0.254	0.002 x0.010	---
3	TO-5	Gold	Flake	0.051 x0.010	0.002 x0.010	---
3	TO-18	Gold	Flake	0.051 x0.254	0.002 x0.010	---
3	FPML	Gold	Flake	0.051 x0.254	0.002 x0.010	---
3	FPLL	Gold	Flake	0.051 x0.254	0.002 x0.0.0	---
3	CDIP	Gold	Flake	0.051 x0.254	0.002 x0.010	---

[a]flatpack witn metal lid, 16 lead

[b]flatpack with ceram. lid, 14 lead

[c]ceramic dual in-line package, 16 lead

continued

TABLE 3 continued

GROUP II SPECIMENS

NUMBER OF SPECIMENS	PACKAGE TYPE	PARTICLE CHARACTERIZATION				
		MATERIAL	SHAPE	NOMINAL DIAMETER (mm)	NOMINAL DIAMETER (in)	CALCULATED NOMINAL MASS (μg)
3	TO-3	Aluminum	Sphere	0.127	0.005	2.9
3	TO-5	Aluminum	Sphere	0.127	0.005	2.9
3	TO-18	Aluminum	Sphere	0.127	0.005	2.9
3	FPML	Aluminum	Sphere	0.127	0.005	2.9
3	FPCL	Aluminum	Sphere	0.127	0.005	2.9
3	CDIP	Aluminum	Sphere	0.127	0.005	2.9
3	TO-3	Aluminum	Sphere	0.076	0.003	0.63
3	TO-5	Aluminum	Sphere	0.076	0.003	0.63
3	TO-18	Aluminum	Sphere	0.076	0.003	0.63
3	FPML	Aluminum	Sphere	0.076	0.003	0.63
3	FPCL	Aluminum	Sphere	0.076	0.003	0.63
3	CDIP	Aluminum	Sphere	0.076	0.003	0.63
3	TO-3	Aluminum	Sphere	0.025	0.001	0.023
3	TO-5	Aluminum	Sphere	0.025	0.001	0.023
3	TO-18	Aluminum	Sphere	0.025	0.001	0.023
3	FPML	Aluminum	Sphere	0.025	0.001	0.023
3	FPCL	Aluminum	Sphere	0.025	0.001	0.023
3	CDIP	Aluminum	Sphere	0.025	0.001	0.023
3	TO-3	Aluminum	Flake	0.051 x0.254	0.002 x0.010	---
3	TO-5	Aluminum	Flake	0.051 x0.254	0.002 x0.010	---
3	TO-18	Aluminum	Flake	0.051 x0.254	0.002 x0.010	---
3	FPML	Aluminum	Flake	0.051 x0.254	0.002 x0.010	---
3	FPLL	Aluminum	Flake	0.051 x0.254	0.002 x0.010	---
3	CDIP	Aluminum	Flake	0.051 x0.254	0.002 x0.010	---

TABLE 3 continued

GROUP II SPECIMENS

NUMBER OF SPECIMENS	PACKAGE TYPE	PARTICLE CHARACTERIZATION				
		MATERIAL	SHAPE	NOMINAL DIAMETER (mm)	NOMINAL DIAMETER (in)	CALCULATED NOMINAL MASS (ug)
3	TO-3	Lead	Sphere	0.076	0.003	2.6
3	TO-5	Lead	Sphere	0.076	0.003	2.6
3	TO-18	Lead	Sphere	0.076	0.003	2.6
3	FPML	Lead	Sphere	0.076	0.003	2.6
3	FPLL	Lead	Sphere	0.076	0.003	2.6
3	CDIP	Lead	Sphere	0.076	0.001	2.6
3	TO-3	Lead	Sphere	0.025	0.001	0.098
3	TO-5	Lead	Sphere	0.025	0.001	0.098
3	TO-18	Lead	Sphere	0.025	0.001	0.098
3	FPML	Lead	Sphere	0.025	0.001	0.098
3	FPLL	Lead	Sphere	0.025	0.001	0.098
3	CDIP	Lead	Sphere	0.025	0.001	0.098
3	TO-3	Silicon-Aluminum	Sphere	0.127	0.005	2.7
3	TO-5	Silicon-Aluminum	Sphere	0.127	0.005	2.7
3	TO-18	Silicon-Aluminum	Sphere	0.127	0.005	2.7
3	FPML	Silicon-Aluminum	Sphere	0.127	0.005	2.7
3	FPLL	Silicon-Aluminum	Sphere	0.127	0.005	2.7
3	CDIP	Silicon-Aluminum	Sphere	0.127	0.005	2.7
9	TO-3	Unseeded				
9	TO-5	Unseeded				
9	TO-10	Unseeded				
9	FPML	Unseeded				
9	FPLL	Unseeded				
9	CDIP	Unseeded				

TABLE 4

GROUP III SPECIMENS

NUMBER OF SPECIMENS	PACKAGE TYPE	PARTICLE CHARACTERIZATION				
		MATERIAL	SHAPE	NOMINAL DIAMETER (mm)	NOMINAL DIAMETER (in)	CALCULATED NOMINAL MASS (μg)
25	[a] 1 1/4 x 1 1/4 MB	Gold	Sphere	0.0457	0.0018	1.0
25	[b] 1 x 1 MB	Gold	Sphere	0.0356	0.0014	0.5
25	[c] 1 x 1 CFP	Gold	Sphere	0.0356	0.0014	0.5
25	[d] 5/8 x 5/8 MB	Gold	Sphere	0.0254	0.001	0.17
25	TO-8	Gold	Sphere	0.0254	0.001	0.17
4	1 1/4 x 1 1/4 MB	Gold	Sphere	0.457	0.0018	1.0
4	1 1/4 x 1 1/4 MB	Unseeded				
4	1 x 1 MB	Gold	Sphere	0.0356	0.0014	0.5
4	1 x 1 MB	Gold	Wire			0.5
4	1 x 1 CFP	Gold	Sphere	0.0356	0.0014	0.5
4	1 x 1 CFP	Unseeded				
4	5/8 x 5/8 MB	Gold	Sphere	0.0254	0.001	0.17
4	5/8 x 5/8 MB	Gold	Wire			0.17
4	TO-8	Gold	Wire			0.17
4	TO-8	Unseeded				

[a] 32 x 32 mm (1.25 x 1.25 in) metal butterfly package

[b] 25 x 25 mm (1 x 1 in) metal butterfly package

[c] 25 x 25 mm ceramic flatpack

[d] 16 x 16 mm (0.63 x 0.63 in) metal butterfly package

TABLE 5

SUMMARY OF SEVEN PIND TRIALS CONDUCTED BY NBS ON GROUP II SPECIMENS

Trial No.	Shaker Used	Pre-Test Shock	Co-Shock[a]	Detection System	Test Frequency (Hz)	Acceleration Level g_n	Detection Score[b] for 198 Seeded Specimens (%)	Detection Score[b] for 54 Unseeded Specimens (%)
1	NBS	Apparatus C	System B	System B	60	±10	48	24
2	NBS	Apparatus C	System B	System B	43-96[c]	±10	50	24
3	NBS	Apparatus C	System B	System B	43-96[c]	±20	55	26
4	NBS	Apparatus C	System B (applied every 10 Hz)	System B	sweep from 250-40	±10	45	22
5	System A	Apparatus C	Manual w/ copper rod	System A	60	±10	39	17
6	NBS	Apparatus C	System B	System B	60	±10	43	22
7	System A	Manual table tap	Manual w/ copper rod	System A	60	±10	38	15

[a]A maximum of three co-shocks was applied during each run, except in the case of swept-frequency trials.

[b]The detection score, in percent, is defined as 100 times the quotient of the number of specimens in which a particle was detected and the number of specimens tested.

[c]The frequency used within this range for a given package type was determined in accordance with the Test Method.

TABLE 6 PRELIMINARY TESTS WITH GROUP I SPECIMENS

TEST PURPOSE	TEST CONDITIONS Acceleration (g_n)	TEST CONDITIONS Frequency (Hz)	COUPLANT	PACKAGE	SEED Diameter (mm)	COMMENTS
Output of Transducer-Amplifier Combinations with various couplants	±10	25-250 2-min sweep	D,E,F	TO-5	gold sphere (0.051)	for each couplant, 2 runs with 3 specimens
				TO-18	gold sphere (0.10)	
				metal flatpack	lead sphere (0.076)	
Output of Transducer-Amplifier Combination for various seed particle masses, package configurations, and acceleration levels	±5 ±10 ±20	20-250 25-250 30-350 2-min sweep	D	TO-5	gold sphere (0.051, 0.10) 2 each lead sphere (0.076, 0.152) 2 each	for each acceleration level, 3 runs with 17 specimens
				TO-18	gold sphere (0.051) 1 (0.10) 2 lead sphere (0.076) 1 (0.152) 2	
				metal flatpack	gold sphere (0.051, 0.10) 1 each lead sphere (0.076) 1	
Lock-Up Tendency for various acceleration levels and frequencies	±3,±5	20	D	TO-18	gold sphere (0.051)	for each of 14 combinations of conditions (acceleration level and frequency), 5 runs with 4 specimens
	±3,±5 ±10, ±20	30,60, 100			lead sphere (0.076)	
				TO-5	gold sphere (0.051)	
				metal flatpack	gold sphere (0.051)	
Repeatability of Amplitude-Frequency Tests	±10	25-250 2-min sweep	D	TO-5	gold sphere (0.051)	7 runs

TABLE 7

SUMMARY OF THREE PIND TRIALS CONDUCTED BY SUPPLIER ON GROUP II SPECIMENS FOLLOWING NBS TRIALS 1 THROUGH 7[a]

Trial No.	Shaker Used	Pre-Test Shock	Co-Shock	Detection System	Test Frequency (Hz)	Acceleration Level g_n	Detection Score for 198 Seeded Specimens (%)	Detection Score for 54 Unseeded Specimens (%)
8	System A	manual table tap	manual with copper rod	System A	60	±10	40	11
9	System D	System D, 1500 g_n	System D, 1000 g_n	System D	60	±10	32	0
10	System D	System D, 1500 g_n	System D, 1000 g_n	System D	in accordance with data in Method 2020	±20	34	2

[a] System D refers to a newly available semi-automatic system incorporating means for imparting pre-test shock and co-shock accelerations to the specimen.

TABLE 8

DETECTION SCORES (IN PERCENT) FOR TEN TRIALS WITH GROUP II SPECIMENS

Particle Material and Size (mm)	Number of Specimens	Trial 1 %	Trial 2 %	Trial 3 %	Trial 4 %	Trial 5 %	Trial 6 %	Trial 7 %	NBS Overall %	Trial 8 %	Trial 9 %	Trial 10 %	Supplier Overall %	Overall %
gold sphere, 0.025	18	33	39	39	28	33	22	28	32	33	22	28	28	31
gold sphere, 0.051	18	44	56	50	39	28	44	22	40	33	28	28	30	37
gold sphere, 0.10	18	61	50	61	56	61	44	50	55	61	56	50	56	55
gold flake, 0.051 x 0.25	18	50	56	61	56	50	61	67	57	50	44	44	46	54
aluminum sphere, 0.025	18	33	17	39	22	11	17	06	21	06	06	0	04	16
aluminum sphere, 0.076	18	44	50	44	39	28	39	22	38	22	11	11	15	31
aluminum sphere, 0.13	18	44	44	44	39	33	39	50	42	33	22	33	29	38
aluminum flake 0.051 x 0.25	18	67	78	67	67	67	61	56	66	61	61	61	61	65
lead sphere, 0.025	18	44	50	56	28	22	22	22	35	28	11	28	22	31
lead sphere, 0.076	18	61	61	72	67	67	78	56	66	61	50	50	54	56
silicon-aluminum sphere, 0.13	18	44	44	67	61	33	50	44	49	50	44	39	44	48
TRIAL DETECTION SCORES		48	50	55	45	39	43	38	45	40	32	34	35	42

TABLE 9

CORRECTED DETECTION SCORES (IN PERCENT) FOR TEN TRIALS WITH GROUP II SPECIMENS[a]

Particle Material and Size (mm)	Number of Specimens	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7	NBS Overall	Trial 8	Trial 9	Trial 10	Supplier Overall	Overall
		%	%	%	%	%	%	%	%	%	%	%	%	%
gold sphere, 0.025	11	55	64	64	45	55	36	45	52	55	36	45	45	50
gold sphere, 0.051	13	62	77	69	54	38	62	31	56	46	38	38	41	52
gold sphere, 0.10	12	92	83	92	83	92	67	75	83	92	83	75	83	83
gold flake, 0.051 x 0.25	13	69	77	85	77	69	85	92	79	69	62	62	64	75
aluminum sphere, 0.025	12	50	25	58	33	17	25	08	33	08	08	0	05	24
aluminum sphere, 0.076	10	80	90	80	70	50	70	40	69	40	20	20	27	56
aluminum sphere, 0.13	10	80	80	80	70	60	70	90	76	60	40	60	53	69
aluminum flake 0.051 x 0.25	16	75	88	75	75	75	69	63	74	69	69	69	69	73
lead sphere, 0.025	11	73	82	91	45	36	36	36	57	45	18	45	36	51
lead sphere, 0.076	17	65	65	76	71	71	82	59	70	65	53	53	57	66
silicon aluminum sphere, 0.13	14	57	57	86	79	43	64	57	63	64	57	50	57	61
TRIAL DETECTION SCORES		68	71	78	65	56	62	55	65	57	46	48	50	61

See 3.1 for an explanation of this table.

TABLE 10

AGREEMENT SCORES (IN PERCENT) FOR TEN TRIALS WITH GROUP II SPECIMENS IN ACCORDANCE WITH THE MODIFIED CHARACTERIZATION[a]

Particle Material and Size (mm)	Number of Specimens	Trial 1 %	Trial 2 %	Trial 3 %	Trial 4 %	Trial 5 %	Trial 6 %	Trial 7 %	NBS Overall %	Trial 8 %	Trial 9 %	Trial 10 %	Supplier Overall %	Overall %
gold sphere 0.025	18	72	77	77	72	61	61	67	70	72	61	67	67	69
gold sphere, 0.051	18	72	77	77	67	56	72	50	67	61	56	56	58	64
gold sphere, 0.10	18	94	89	94	89	94	77	83	89	94	89	83	89	89
gold flake, 0.051 x 0.25	18	77	83	89	83	77	89	89	84	77	72	72	74	81
aluminum sphere, 0.025	18	67	50	72	56	44	50	39	54	39	39	33	37	49
aluminum sphere, 0.076	18	89	94	89	83	72	83	67	82	67	56	56	60	75
aluminum sphere, 0.13	18	89	89	89	83	77	83	94	86	77	67	77	74	83
aluminum flake 0.051 x 0.25	18	77	89	77	77	77	77	67	77	72	72	72	72	76
lead sphere, 0.025	18	83	89	94	67	61	61	61	74	67	50	67	61	70
lead sphere, 0.076	18	67	67	77	72	72	83	61	71	67	56	56	60	68
silicon aluminum sphere, 0.13	18	67	67	89	83	56	72	67	72	72	67	61	67	70
TRIAL AGREEMENT SCORES		78	79	84	76	68	73	74	75	70	62	64	65	72

[a] See 3.1 for an explanation of the modified characterization.

TABLE 11

PIND TRIAL ON GROUP III SPECIMENS

Col. 1 Specimen size, in. (mm), Specimen Description, Seed Particle Composition and Shape, Mass, μg	Col. 2 No. of Specimens	Col. 3 No. of Specimens with Particle Detected	Col. 4 Detection Score 100 (col 3/col 4), %
1 1/4 x 1 1/4 (32 x 32) metal butterfly gold sphere, 1	28	4	14
1 x 1 (25 x 25) metal butterfly gold sphere, 0.5	28	3	11
1 x 1 (25 x 25) ceramic flatpack gold sphere, 0.5	29	25	86
5/8 x 5/8 (16 x 16) metal butterfly gold sphere, 0.17	27	1	4
TO-8 can gold sphere, 0.17	24	15	63
1 x 1 (25 x 25) metal butterfly gold wire, 0.5	4	1	25
5/8 x 5/8 (16 x 16) metal butterfly gold wire, 0.17	4	0	0
TO-8 can gold wire, 0.17	4	2	50
1-1/4 x 1-1/4 (32 x 32) metal butterfly no seed	4	0	0
1 x 1 (25 x 25) ceramic flatpack no seed	4	2	50
TO-8 can no seed	4	2	50
TOTALS (seeded)	148	51	34
TOTALS (unseeded)	12	4	33

TABLE 12

TIME TO PARTICLE LOCK UP (s) AS A FUNCTION OF ACCELERATION LEVEL AND FREQUENCY FOR A SEEDED TO-18 SPECIMEN PACKAGE[a]

Frequency (Hz) \ Accleration level (g_n)	±3	±5	±10	±20
20	13	4	---	---
40	17	8	1.6	1.0
60	20	20	8.4	1.0
100	20	20	18.2	8.8

[a]If the particle did not lock up, the test was terminated at 20 s. The times are averages of five tests.

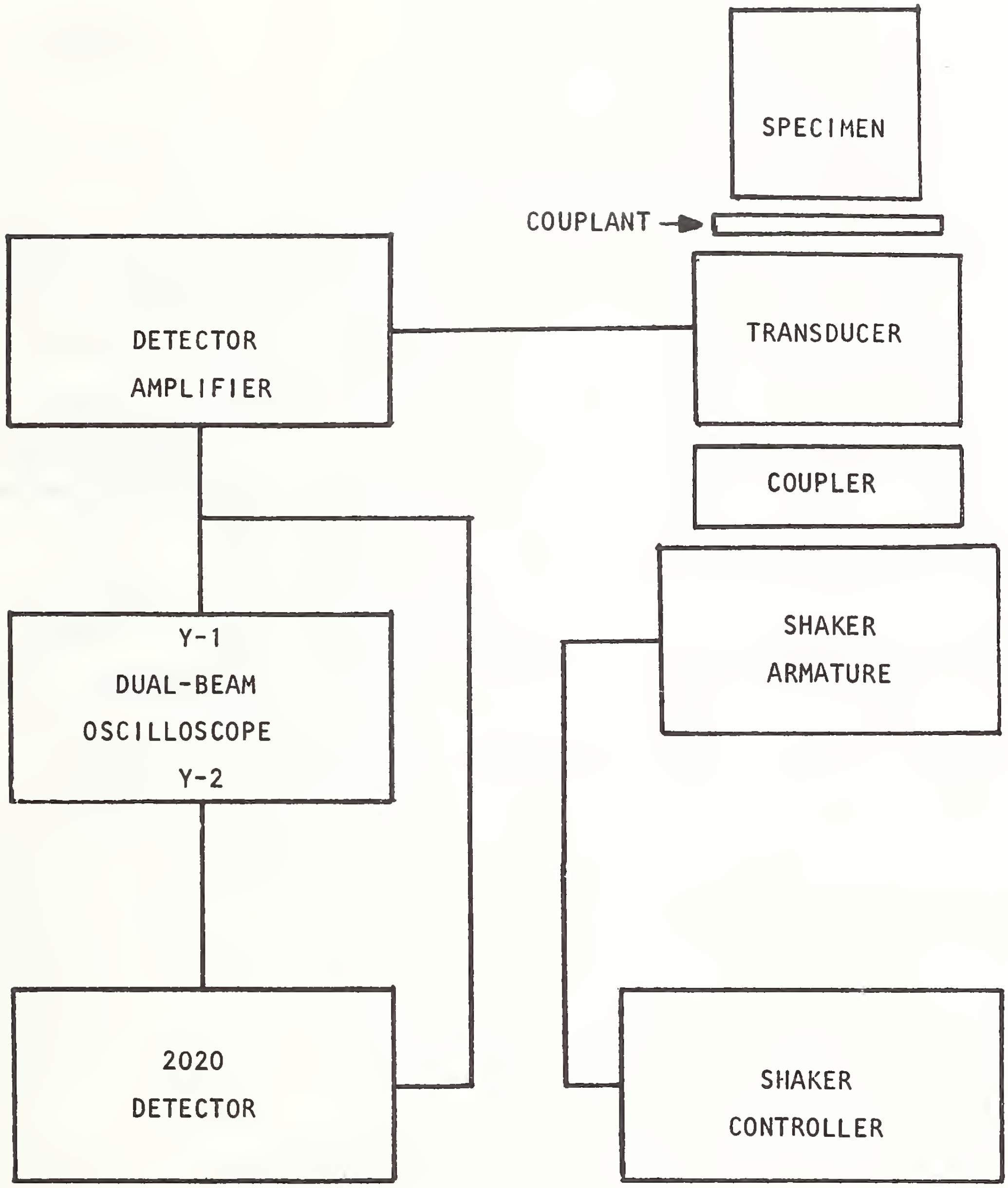


FIGURE 1: Test configuration 1, incorporating commercial system components (shaker and shaker control, ultrasonic detection transducer, detector modules), threshold level detector built in-house in accordance with Test Method 2020, and oscilloscope with camera.

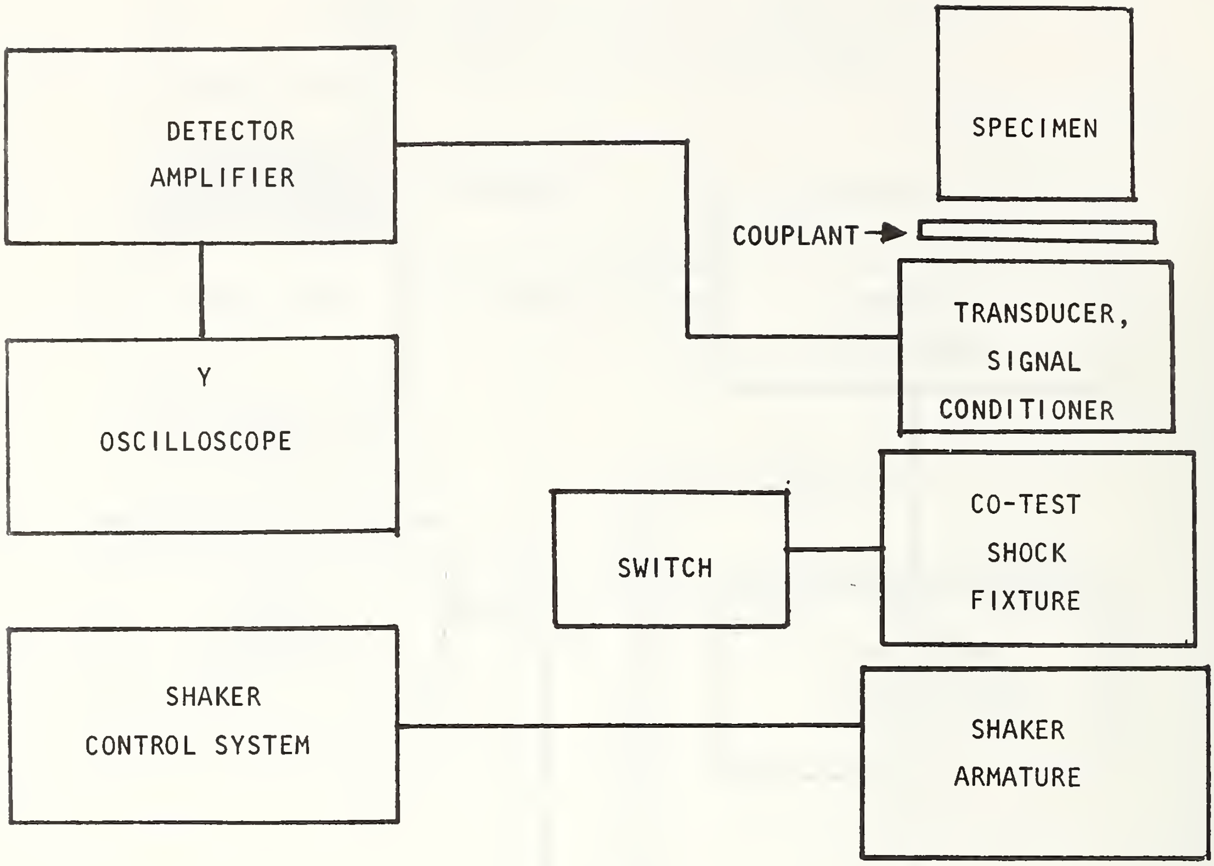


FIGURE 2: Test configuration 2, incorporating commercial system B components (combination co-shock fixture and ultrasonic detection transducer with amplifier, co-shock push-button switch, detector module with co-shock control), shaker and shaker control, and oscilloscope with camera. The system B components are identified in table 1.

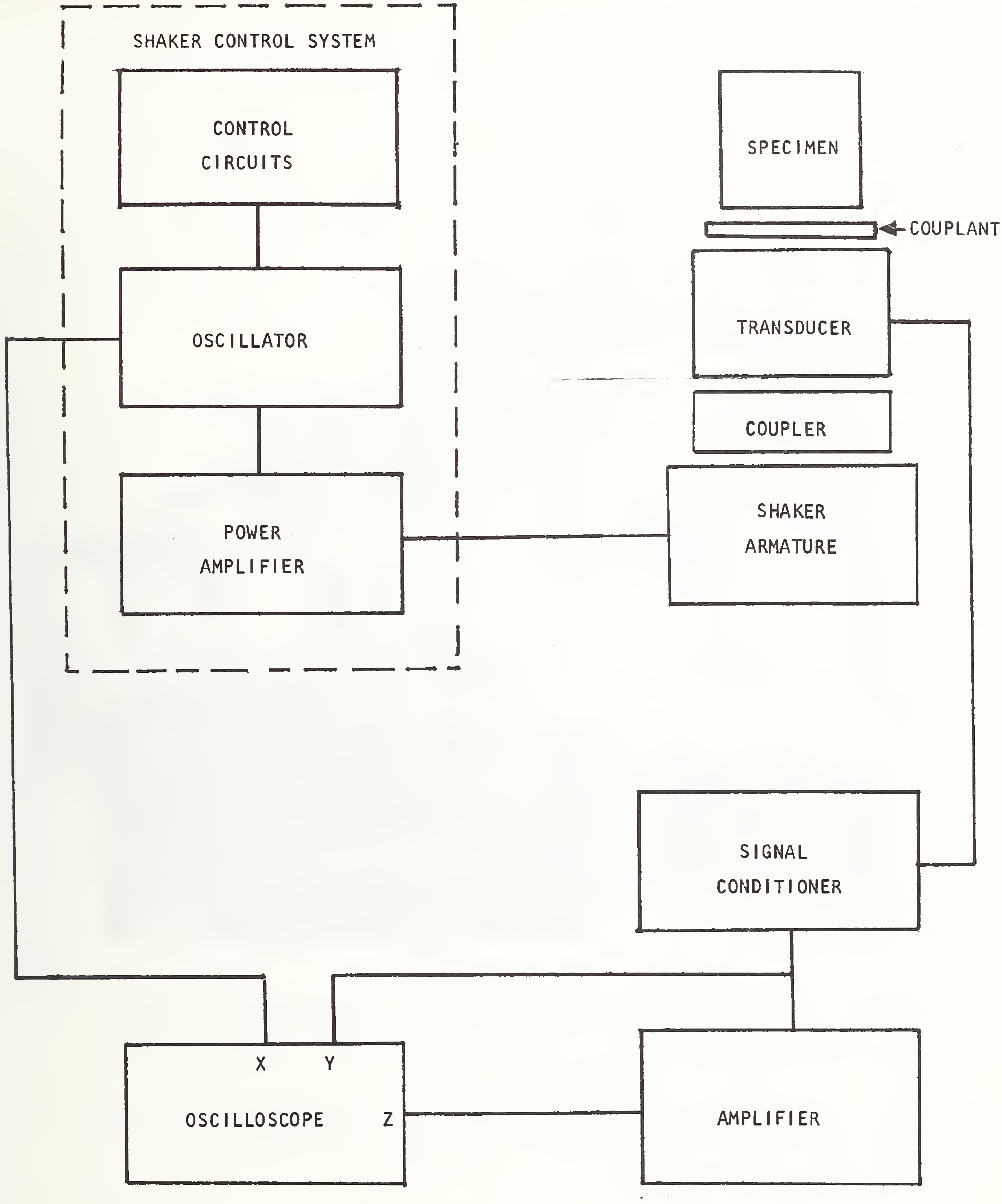


FIGURE 3: Test configuration 3, for amplitude-frequency plots, incorporating commercial system A components.

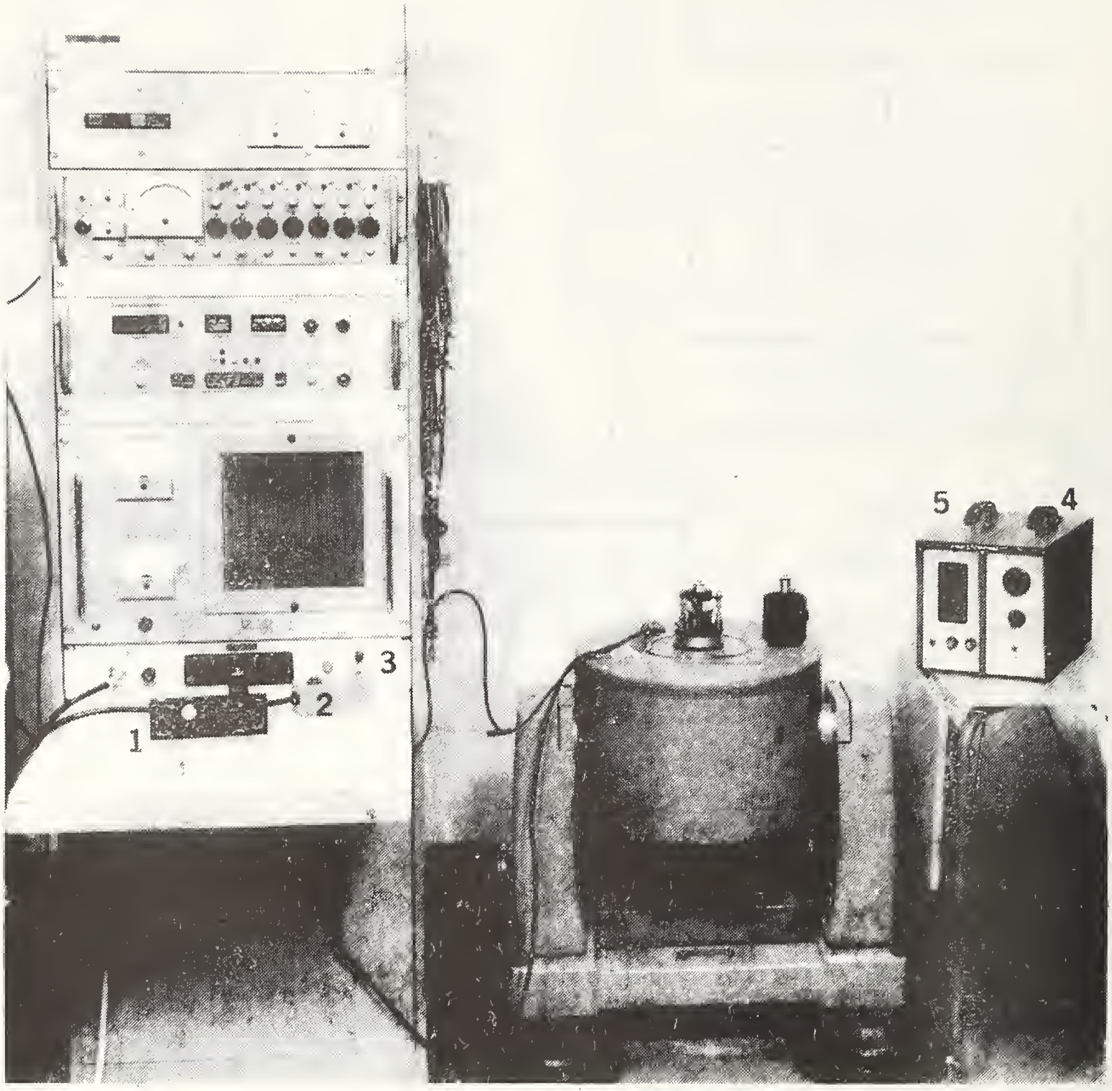


FIGURE 4: Overall view of the NBS vibration exciter system, with various commercial PIND apparatus. On the console table can be seen the pre-test shock apparatus C (at 1); to its right (at 2) is a small control box with a push-button switch for actuating the co-shock apparatus, System B. Behind these components (at 3) is the rack-mounted detector module of System B. Apparatus on the exciter is shown in close-up in figure 5 and identified in the caption for that figure. The two instruments at the right are the exciter power supply and controller for the System A exciter (4) and the System A detector module (5).

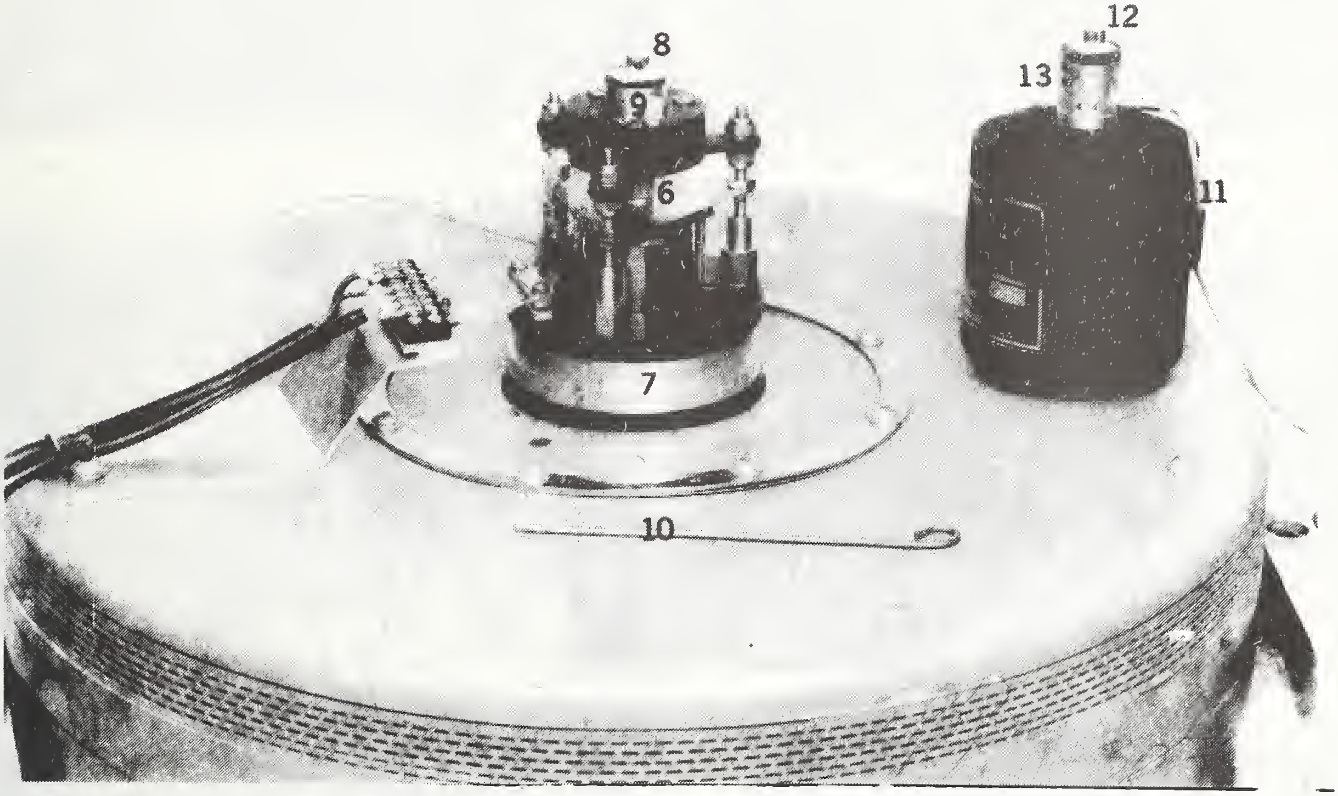


FIGURE 5: Close-up view of the NBS exciter, with various commercial PIND apparatus. The System B co-shock fixture (6) is shown mounted on the armature of the NBS exciter (7). A specimen device (8) is shown mounted on the System B ultrasonic detection transducer (9). The manual co-shock tool (10) used with System A gives some idea of scale; it is approximately 150 mm long. The System A vibration exciter sits to the right of the large exciter's armature (at 11), with another specimen device (12) mounted on top of its ultrasonic transducer (13).

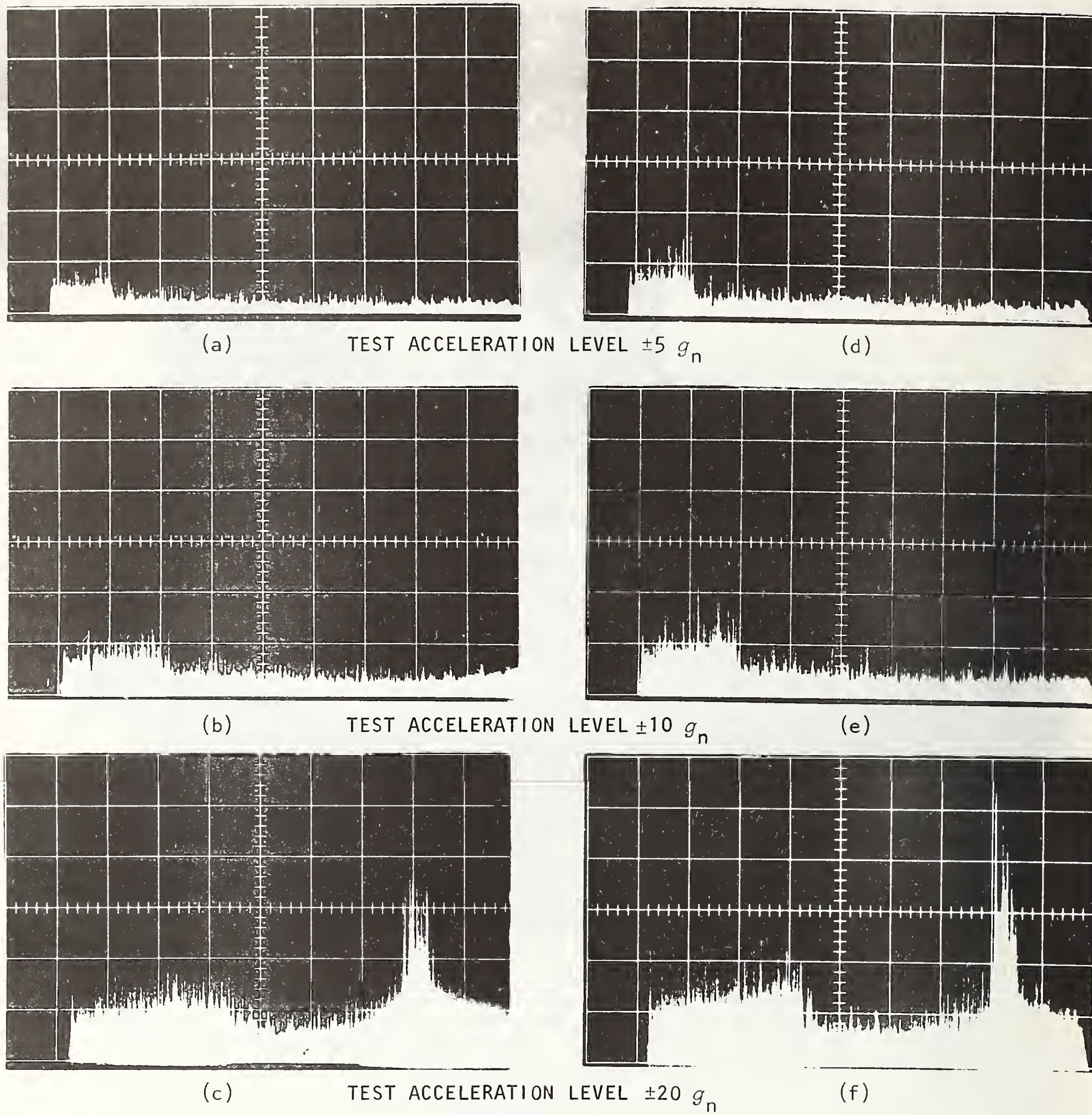
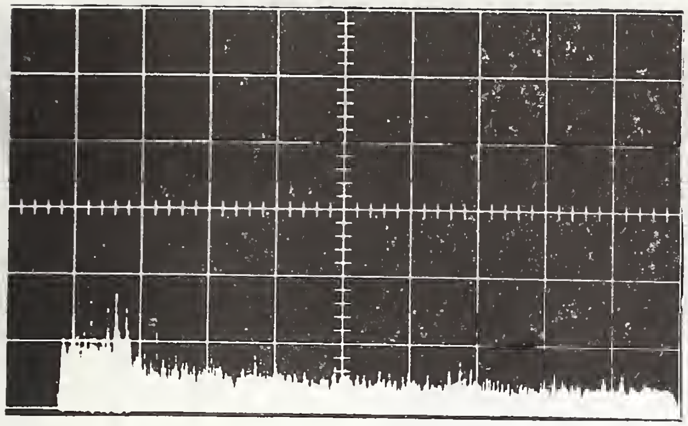
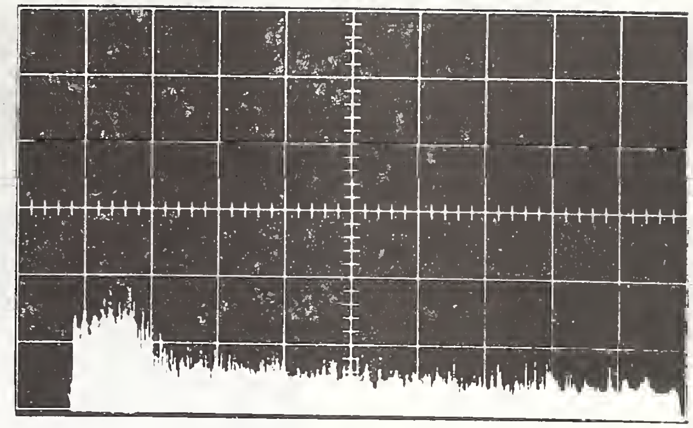
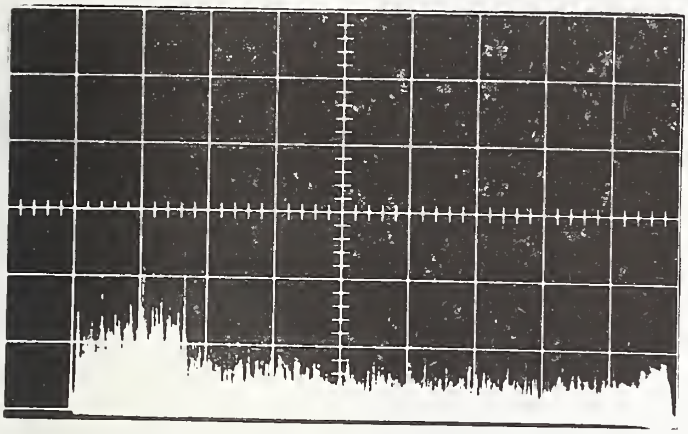


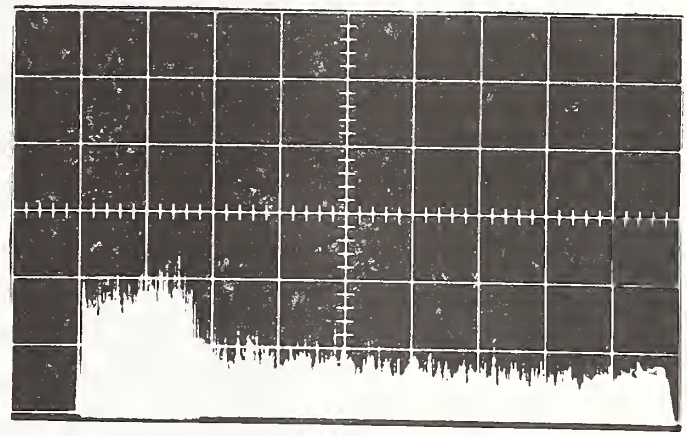
FIGURE 6: Photographs of oscilloscope screen traces generated at three test acceleration levels by the amplitude-frequency plot technique for four TO-5 specimen packages having different seed particles. For photographs a, b, and c, the seed is a gold sphere 0.051 mm in diameter, and the deflection sensitivity is one volt per division. For photographs d, e, and f, the seed is a gold sphere 0.102 mm in diameter, and the deflection sensitivity is five volts per division. For photographs g, h, and i, the seed is a lead sphere 0.076 mm in diameter, and the deflection sensitivity is one volt per division. For photographs j, k, and l, the seed is a lead sphere 0.152 mm in diameter, and the deflection sensitivity is five volts per division. For all photographs, the frequency scale is 25 Hz per division, and the sweep time represented is 2 min. The enhanced trace levels in the region of 200 Hz (about two divisions from the right-hand edge) seen in c, f, i, and l are the result of mechanical resonance of the coupler.



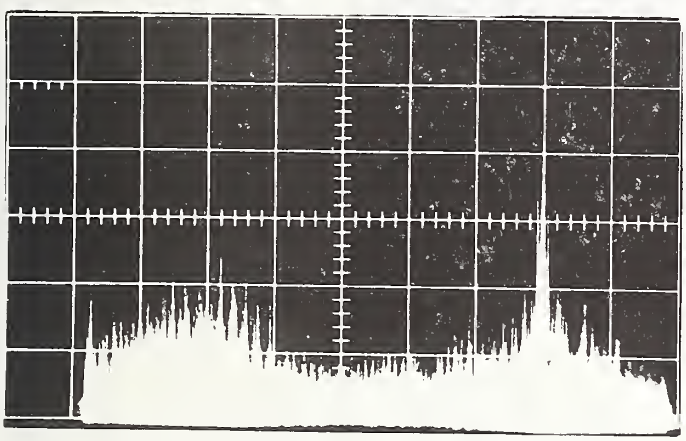


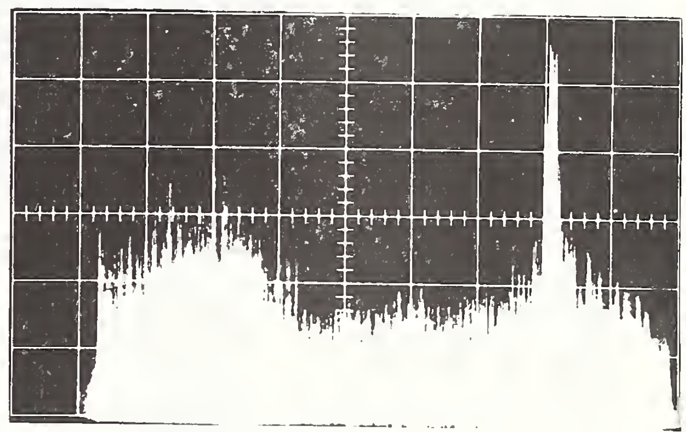
(g) TEST ACCELERATION LEVEL ±5 g_n (j)





(h) TEST ACCELERATION LEVEL ±10 g_n (k)





(i) TEST ACCELERATION LEVEL ±20 g_n (l)

FIGURE 6: Photographs of oscilloscope screen traces generated at three test acceleration levels by the amplitude-frequency plot technique for four TO-5 specimen packages having different seed particles. For photographs a, b, and c, the seed is a gold sphere 0.051 mm in diameter, and the deflection sensitivity is one volt per division. For photographs d, e, and f, the seed is a gold sphere 0.102 mm in diameter, and the deflection sensitivity is five volts per division. For photographs g, h, and i, the seed is a lead sphere 0.076 mm in diameter, and the deflection sensitivity is one volts per division. For photographs j, k, and l, the seed is a lead sphere 0.152 mm in diameter, and the deflection sensitivity is five volts per division. For all photographs, the frequency scale is 25 Hz per division, and the sweep time represented is 2 min. The enhanced trace levels in the region of 200 Hz (about two divisions from the right-hand edge) seen in c, f, i, and l are the result of mechanical resonance of the coupler.

PIND TEST DATA SHEET

DATE ________ 1978

TEST IDENTIFICATION ________

OPERATOR ________

SHEET ____ OF ____

APPARATUS

PRE-TEST SHOCK ________

CO-SHOCK ________

DETECTION SENSITIVITY VERIFIED ___ YES ___ NO

SIGNAL-FREE TEST DURATION ____ MIN

NOISE LEVEL ______ mV PEAK-TO-PEAK

TEST CONDITIONS

SWEEP FROM ___ Hz TO ___ Hz

SINGLE FREQUENCY ___ Hz

ACCELERATION ____ g_n PEAK-TO-PEAK

PACKAGE TYPE	SPECIMEN NO.	SEED MATERIAL: Al, Au, Pb, Si-Al SIZE (mm) SHAPE: F = flake, S = sphere, W = wire	TIME OF DETECTION 0 = before any co-shock 1 = after one co-shock 2 = after two co-shocks 3 = after three co-shocks x = no detection	DETECTION MEANS AND LEVEL INDICATION A = audible signal L = level-indicator pilot light V = visual observation of oscilloscope trace vs = very small detection signal s = small signal m = medium signal l = large signal	COMMENTS

FIGURE 7: PIND test data sheet.

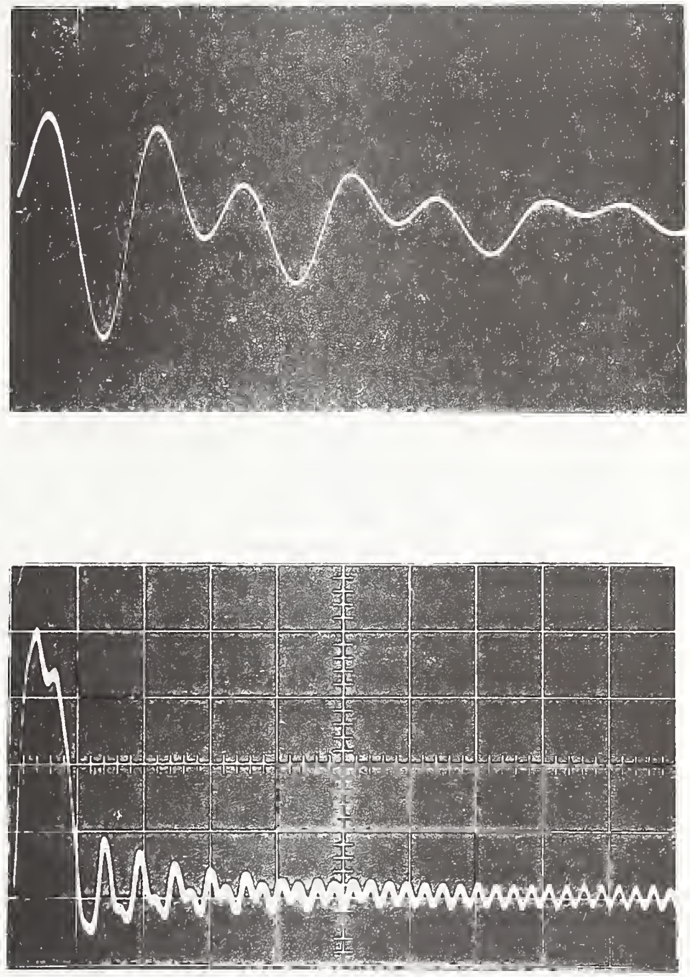


FIGURE 8: Photographs of oscilloscope screen traces of shock acceleration waveforms imparted to the specimen by pre-test shock apparatus C (upper photograph) and the system B co-shock apparatus, as sensed by a test accelerometer. For both photographs, the deflection sensitivity is 1000 g_n per division, and the time base 50 μs per division. Corrections that have to be taken into account in interpreting these photographs are discussed in 3.3.1 and 3.3.2.

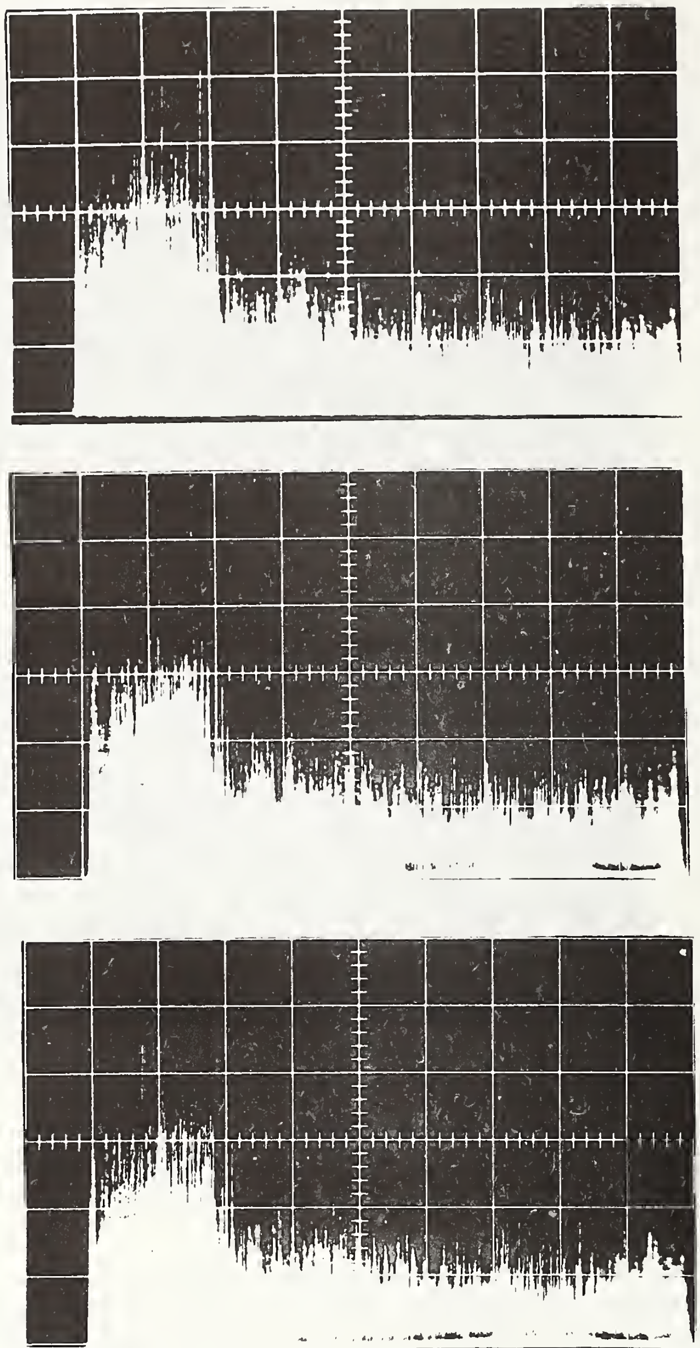
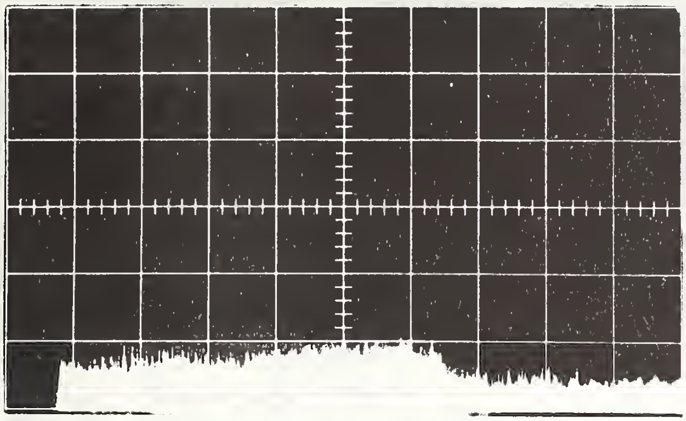
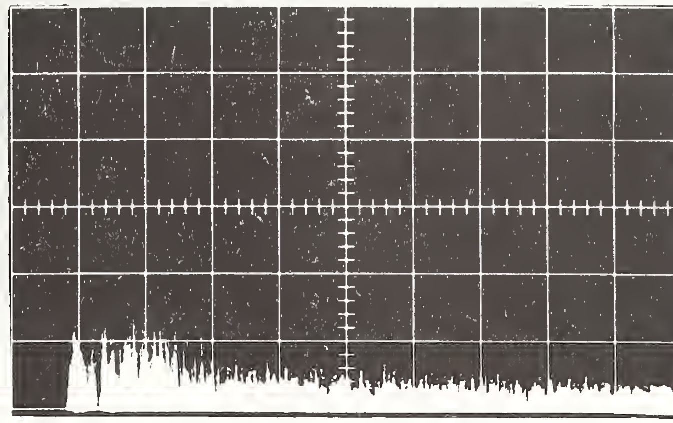
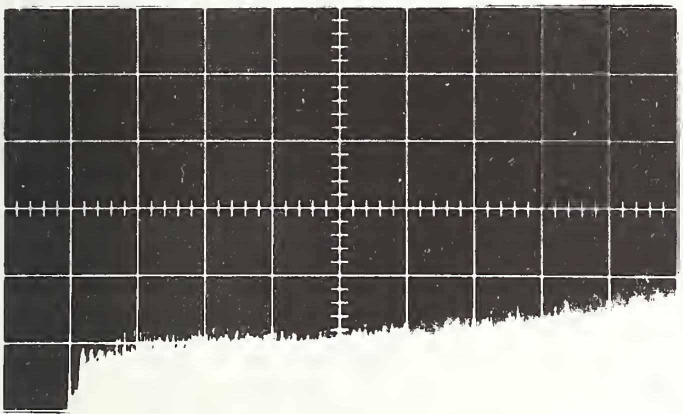


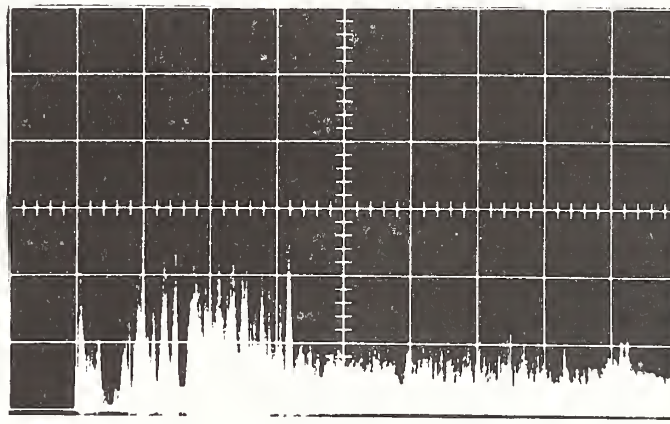
FIGURE 9: Photographs of oscilloscope screen traces generated at three different times by the amplitude-frequency plot technique for the same specimen under the same test conditions. Comparison of the traces provides a rough check on the repeatability of the technique and associated apparatus, as discussed in 3.4. The specimen is a TO-5 package seeded with a gold sphere 0.051 mm in diameter. The deflection sensitivity for the photographs is 200 mV per division, and the frequency scale is 25 Hz per division; the sweep time represented is 2 min. The acceleration level was ±10 g_n.



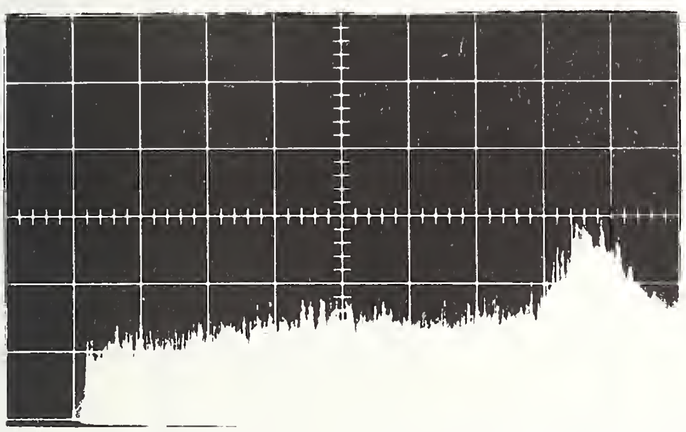


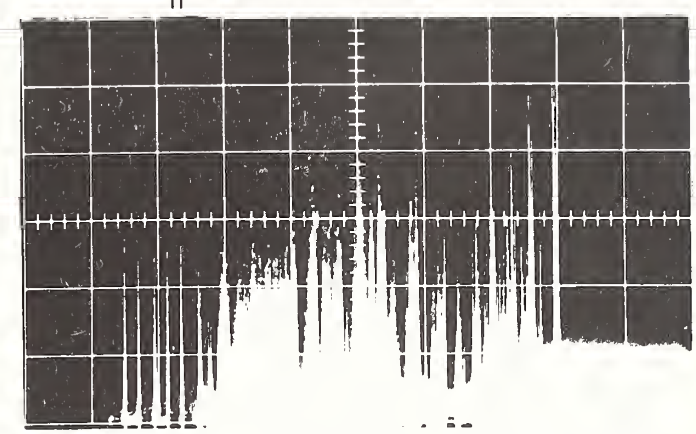
(a) TEST ACCELERATION LEVEL ±5 g_n (d)





(b) TEST ACCELERATION LEVEL ±10 g_n (e)





(c) TEST ACCELERATION LEVEL ±20 g_n (f)

FIGURE 10: Photographs of oscilloscope screen traces generated at three test acceleration levels by the amplitude-frequency plot technique for two different package types, each with the same seed, a gold sphere 0.051 mm in diameter. For photographs a, b, and c, the specimen represented is a metal flatpack. For photographs d, e, and f, the specimen is a TO-18 package. For all photographs, the deflection sensitivity is one volt per division, the frequency scale is 25 Hz per division, and the sweep time represented is 2 min. Gaps in the trace are particularly evident in photographs e and f. These gaps each indicate that the seed particle had become temporarily immobilized and represent delays between the time the camera shutter was closed and the time the frequency sweep was interrupted so that co-shock excitation could be imparted to the specimen in an attempt to free the particle (see 3.4).

APPENDIX I

TRIAL I RESULTS BY PACKAGE TYPE AND SEED PARTICLE OF PIND TESTS ON GROUP II SPECIMENS

TRIAL CONDITIONS - Frequency: 60 Hz Acceleration: $\pm 10\ g_n$ Configuration: 2

	NUMBER OF SPECIMENS FOR WHICH DETECTIONS WERE POSITIVE [a]											SEEDED		UNSEEDED	
PARTICLE	GOLD				ALUMINUM				LEAD		SI-AL			NONE	
SHAPE	SPHERE	SPHERE	SPHERE	FLAKE	SPHERE	SPHERE	SPHERE	FLAKE	SPHERE	SPHERE	SPHERE	TOTALS	DETECTION SCORE (%)		DETECTION SCORE (%)
SIZE (mm)	0.025	0.051	0.10	0.051 × 0.25	0.025	0.051	0.13	0.051 × 0.25	0.025	0.076	0.13				
PACKAGE TYPE															
TO-3	2	3	2	0	1	2	3	3	2	2	2	22	67	3	33
TO-5	1	2	2	1	2	3	1	3	3	2	1	21 (33)	64	5 (9)	56
TO-18	3	2	3	3	2	3	2	3	3	3	3	30 (33)	91	4 (9)	44
FLATPACK, METAL LID	0	0	3	2	0	0	0	1	0	0	2	8 (33)	24	0 (9)	0
FLATPACK, CERAMIC LID	0	0	0	3	0	0	2	1	0	2	0	8 (33)	24	1 (9)	11
CERAMIC DIP	0	1	1	0	1	0	0	1	0	2	0	6 (33)	18	0 (9)	0
TOTALS	6 (18)	8 (18)	11 (18)	9 (18)	6 (18)	8 (18)	8 (18)	12 (18)	8 (18)	11 (18)	8 (18)	95 (198)	48	13 (54)	24
DETECTION SCORE (%)	33	44	61	50	33	44	44	67	44	61	44		48		24

[a] The total number of specimens tested is given in parentheses.

APPENDIX I

TRIAL 2 RESULTS BY PACKAGE TYPE AND SEED PARTICLE OF PIND TESTS ON GROUP II SPECIMENS

TRIAL CONDITIONS - Frequency: 43-96 Hz Acceleration: $\pm$ 10 g_n Configuration: 2

	NUMBER OF SPECIMENS FOR WHICH DETECTIONS WERE POSITIVE [a]											SEEDED		UNSEEDED	
PARTICLE	GOLD				ALUMINUM				LEAD		SI-AL			NONE	
SHAPE	SPHERE	SPHERE	SPHERE	FLAKE	SPHERE	SPHERE	SPHERE	FLAKE	SPHERE	SPHERE	SPHERE	TOTALS	DETECTION SCORE (%)		DETECTION SCORE (%)
SIZE (mm)	0.025	0.051	0.10	0.051 × 0.25	0.025	0.051	0.13	0.051 × 0.25	0.025	0.076	0.13				
PACKAGE TYPE															
TO-3	3	3	1	1	0	2	2	3	2	3	1	21 (33)	64	3 (9)	33
TO-5	1	2	2	1	1	3	2	3	3	2	2	22 (33)	67	4 (9)	44
TO-18	3	3	3	3	2	3	2	3	3	3	3	31 (33	94	4 (9)	44
FLATPACK, METAL LID	0	1	3	2	0	0	0	1	0	0	2	9 (33)	27	0 (9)	0
FLATPACK, CERAMIC LID	0	0	0	3	0	1	2	2	1	1	0	10 (33)	30	1 (9)	11
CERAMIC DIP	0	1	1	0	0	0	0	2	0	2	0	6 (33)	18	1 (9)	11
TOTALS	7 (18)	10 (18)	9 (18)	10 (18)	3 (18)	9 (18)	8 (18)	14 (18)	9 (18)	11 (18)	8 (18)	99 (198)	50	13 (54)	24
DETECTION SCORE (%)	39	56	50	56	17	50	44	78	50	61	44		50		24

[a] The total number of specimens tested is given in parentheses.

APPENDIX I

TRIAL 3 RESULTS BY PACKAGE TYPE AND SEED PARTICLE OF PIND TESTS ON GROUP II SPECIMENS

TRIAL CONDITIONS - Frequency: 43-96 Hz Acceleration: $\pm 20\ g_n$ Configuration: 2

NUMBER OF SPECIMENS FOR WHICH DETECTIONS WERE POSITIVE [a]

PARTICLE	GOLD				ALUMINUM				LEAD		SI-AL	SEEDED		UNSEEDED	
SHAPE	SPHERE	SPHERE	SPHERE	FLAKE	SPHERE	SPHERE	SPHERE	FLAKE	SPHERE	SPHERE	SPHERE	TOTALS	DETECTION SCORE (%)	NONE	DETECTION SCORE (%)
SIZE (mm)	0.025	0.051	0.10	0.051 x 0.25	0.025	0.051	0.13	0.051 x 0.25	0.025	0.076	0.13				
PACKAGE TYPE															
TO-3	3	3	2	2	1	2	2	2	2	3	3	25 (33)	76	4 (9)	44
TO-5	2	3	2	1	1	3	2	3	3	3	3	26 (33)	79	4 (9)	44
TO-18	2	2	3	3	3	3	2	3	3	3	3	30 (33)	91	6 (9)	67
FLATPACK, METAL LID	0	0	3	2	0	0	0	2	0	1	2	10 (33)	30	0 (9)	0
FLATPACK, CERAMIC LID	0	0	0	3	0	0	2	1	1	1	0	8 (33)	24	0 (9)	0
CERAMIC DIP	0	1	1	0	2	0	0	1	1	2	1	9 (33)	27	0 (9)	0
TOTALS	7 (18)	9 (18)	11 (18)	11 (18)	7 (18)	8 (18)	8 (18)	12 (18)	10 (18)	13 (18)	12 (18)	108 (198)	55	14 (54)	26
DETECTION SCORE (%)	39	50	61	61	39	44	44	67	56	72	67		55		26

[a] The total number of specimens tested is given in parentheses.

APPENDIX I

TRIAL 4 RESULTS BY PACKAGE TYPE AND SEED PARTICLE OF PIND TESTS ON GROUP II SPECIMENS

TRIAL CONDITIONS - Frequency: 250-40 Hz sweep Acceleration: $\pm$ 10 g_n Configuration: 2

	NUMBER OF SPECIMENS FOR WHICH DETECTIONS WERE POSITIVE [a]											SEEDED		UNSEEDED	
PARTICLE	GOLD				ALUMINUM				LEAD		SI-AL			NONE	
SHAPE	SPHERE	SPHERE	SPHERE	FLAKE	SPHERE	SPHERE	SPHERE	FLAKE	SPHERE	SPHERE	SPHERE	TOTALS	DETECTION SCORE (%)		DETECTION SCORE (%)
SIZE (mm)	0.025	0.051	0.10	0.051 x 0.25	0.025	0.051	0.13	0.051 x 0.25	0.025	0.076	0.13				
PACKAGE TYPE															
TO-3	2	3	1	1	0	2	1	3	1	3	2	19 (33)	58	3 (9)	33
TO-5	1	2	2	1	1	2	2	3	3	2	2	21 (33)	64	3 (9)	33
TO-18	2	1	3	3	2	3	2	3	1	3	3	26 (33)	79	5 (9)	56
FLATPACK, METAL LID	0	0	3	2	0	0	0	1	0	1	2	9 (33)	27	0 (9)	0
FLATPACK, CERAMIC LID	0	0	0	3	0	0	2	1	0	1	1	8 (33)	24	1 (9)	11
CERAMIC DIP	0	1	1	0	1	0	0	1	0	2	1	7 (33)	21	0 (9)	0
TOTALS	5 (18)	7 (18)	10 (18)	10 (18)	4 (18)	7 (18)	7 (18)	12 (18)	5 (18)	12 (18)	11 (18)	90 (198)	45	12 (54)	22
DETECTION SCORE (%)	28	39	56	56	22	39	39	67	28	67	61		45		22

[a] The total number of specimens tested is given in parentheses.

APPENDIX I

TRIAL 5 RESULTS BY PACKAGE TYPE AND SEED PARTICLE OF PIND TESTS ON GROUP II SPECIMENS

TRIAL CONDITIONS - Frequency: 60 Hz Acceleration: $\pm 10\ g_n$ Configuration: 1

NUMBER OF SPECIMENS FOR WHICH DETECTIONS WERE POSITIVE [a]

PARTICLE	GOLD				ALUMINUM				LEAD		SI-AL	SEEDED		UNSEEDED NONE	
SHAPE	SPHERE	SPHERE	SPHERE	FLAKE	SPHERE	SPHERE	SPHERE	FLAKE	SPHERE	SPHERE	SPHERE	TOTALS	DETECTION SCORE (%)		DETECTION SCORE (%)
SIZE (mm)	0.025	0.051	0.10	0.051 x 0.25	0.025	0.051	0.13	0.051 x 0.25	0.025	0.076	0.13				
PACKAGE TYPE															
TO-3	1	2	2	0	0	0	1	3	0	2	2	13 (33)	39	2 (9)	22
TO-5	1	1	2	1	0	2	2	3	3	3	1	19 (33)	58	1 (9)	11
TO-18	3	1	2	3	2	3	2	3	1	3	3	26 (33)	79	4 (9)	44
FLATPACK, METAL LID	0	0	3	2	0	0	0	1	0	1	0	7 (33)	21	0 (9)	0
FLATPACK, CERAMIC LID	0	0	1	3	0	0	1	1	0	1	0	7 (33)	21	1 (9)	11
CERAMIC DIP	1	1	1	0	0	0	0	1	0	2	0	6 (33)	18	1 (9)	11
TOTALS	6 (18)	5 (18)	11 (18)	9 (18)	2 (18)	5 (18)	6 (18)	12 (18)	4 (18)	12 (18)	6 (18)	78 (198)	39	17 (54)	17
DETECTION SCORE (%)	33	28	61	50	11	28	33	67	22	67	33		39		17

[a] The total number of specimens tested is given in parentheses.

APPENDIX I

TRIAL 6 RESULTS BY PACKAGE TYPE AND SEED PARTICLE OF PIND TESTS ON GROUP II SPECIMENS

TRIAL CONDITIONS - Frequency: 60 Hz Acceleration: $\pm 10\ g_n$ Configuration: 2

NUMBER OF SPECIMENS FOR WHICH DETECTIONS WERE POSITIVE [a]

												SEEDED		UNSEEDED	
PARTICLE	GOLD				ALUMINUM				LEAD		SI-AL			NONE	
SHAPE	SPHERE	SPHERE	SPHERE	FLAKE	SPHERE	SPHERE	SPHERE	FLAKE	SPHERE	SPHERE	SPHERE	TOTALS	DETECTION SCORE (%)		DETECTION SCORE (%)
SIZE (mm)	0.025	0.051	0.10	0.051 x 0.25	0.025	0.051	0.13	0.051 x 0.25	0.025	0.076	0.13				
PACKAGE TYPE															
TO-3	1	3	1	1	0	1	2	3	0	3	3	18 (33)	55	3 (9)	33
TO-5	2	2	2	2	1	2	1	3	3	3	1	22 (33)	67	3 (9)	33
TO-18	0	1	1	3	1	3	2	3	1	3	3	21 (33)	64	4 (9)	44
FLATPACK, METAL LID	0	0	3	2	0	0	0	1	0	1	2	9 (33)	27	1 (9)	11
FLATPACK, CERAMIC LID	1	0	0	3	0	0	2	0	0	1	0	7 (33)	21	1 (9)	11
CERAMIC DIP	0	2	1	0	1	1	0	1	0	3	0	9 (33)	27	0 (9)	0
TOTALS	4 (18)	8 (18)	8 (18)	11 (18)	3 (18)	7 (18)	7 (18)	11 (18)	4 (18)	14 (18)	9 (18)	86 (198)	43	12 (54)	22
DETECTION SCORE (%)	22	44	44	61	17	39	39	61	22	78	50		43		22

[a] The total number of specimens tested is given in parentheses.

APPENDIX I

TRIAL 7 RESULTS BY PACKAGE TYPE AND SEED PARTICLE OF PIND TESTS ON GROUP II SPECIMENS

TRIAL CONDITIONS - Frequency: 60 Hz Acceleration: $\pm 10\ g_n$ Configuration: 1

NUMBER OF SPECIMENS FOR WHICH DETECTIONS WERE POSITIVE [a]

PARTICLE	GOLD				ALUMINUM				LEAD		SI-AL	SEEDED		UNSEEDED	
														NONE	
SHAPE	SPHERE	SPHERE	SPHERE	FLAKE	SPHERE	SPHERE	SPHERE	FLAKE	SPHERE	SPHERE	SPHERE	TOTALS	DETECTION SCORE (%)		DETECTION SCORE (%)
SIZE (mm)	0.025	0.051	0.10	0.051 × 0.25	0.025	0.051	0.13	0.051 × 0.25	0.025	0.076	0.13				
PACKAGE TYPE															
TO-3	2	1	2	1	0	0	2	2	0	1	2	13 (33)	39	2 (9)	22
TO-5	2	2	2	3	0	2	2	3	3	2	1	22 (33)	67	2 (9)	22
TO-18	1	0	1	3	1	2	3	3	1	3	3	21 (33)	64	4 (9)	44
FLATPACK, METAL LID	0	0	3	2	0	0	0	0	0	0	2	7 (33)	21	0 (9)	0
FLATPACK, CERAMIC LID	0	0	0	3	0	0	2	1	0	1	0	7 (33)	21	0 (9)	0
CERAMIC DIP	0	1	1	0	0	0	0	1	0	3	0	6 (33)	18	0 (9)	0
TOTALS	5 (18)	4 (18)	9 (18)	12 (18)	1 (18)	4 (18)	9 (18)	10 (18)	4 (18)	10 (18)	8 (18)	76 (198)	38	8 (54)	15
DETECTION SCORE (%)	28	22	50	67	6	22	50	56	22	56	44		38		15

[a] The total number of specimens tested is given in parentheses.

APPENDIX I

TRIAL 8 RESULTS BY PACKAGE TYPE AND SEED PARTICLE OF PIND TESTS ON GROUP II SPECIMENS

TRIAL CONDITIONS - Frequency: 60 Hz Acceleration: $\pm 10\ g_n$ Supplier Trial

NUMBER OF SPECIMENS FOR WHICH DETECTIONS WERE POSITIVE [a]

PARTICLE	GOLD				ALUMINUM				LEAD		SI-AL	SEEDED		UNSEEDED	
														NONE	
SHAPE	SPHERE	SPHERE	SPHERE	FLAKE	SPHERE	SPHERE	SPHERE	FLAKE	SPHERE	SPHERE	SPHERE	TOTALS	DETECTION SCORE (%)		DETECTION SCORE (%)
SIZE (mm)	0.025	0.051	0.10	0.051 x 0.25	0.025	0.051	0.13	0.051 x 0.25	0.025	0.076	0.13				
PACKAGE TYPE															
TO-3	0	1	2	0	0	0	1	3	0	0	2	9 (33)	27	1 (9)	11
TO-5	3	2	2	3	0	1	1	3	3	3	2	23 (33)	70	1 (9)	11
TO-18	1	1	2	3	1	3	2	3	2	3	3	24 (33)	73	4 (9)	44
FLATPACK, METAL LID	0	0	3	0	0	0	0	0	0	2	1	6 (33)	18	0 (9)	0
FLATPACK, CERAMIC LID	1	1	1	3	0	0	2	1	0	1	1	11 (33)	33	0 (9)	0
CERAMIC DIP	1	1	1	0	0	0	0	1	0	2	0	6 (33)	18	0 (9)	0
TOTALS	6 (18)	6 (18)	11 (18)	9 (18)	1 (18)	4 (18)	6 (18)	11 (18)	5 (18)	11 (18)	9 (18)	79 (198)	40	6 (54)	11
DETECTION SCORE (%)	33	33	61	50	06	22	33	61	28	61	50		40		11

[a] The total number of specimens tested is given in parentheses.

APPENDIX I

TRIAL 9 RESULTS BY PACKAGE TYPE AND SEED PARTICLE OF PIND TESTS ON GROUP II SPECIMENS

TRIAL CONDITIONS - Frequency: 60 Hz Acceleration: $\pm 10\ g_n$ Supplier Trial

PARTICLE	NUMBER OF SPECIMENS FOR WHICH DETECTIONS WERE POSITIVE [a]: GOLD				ALUMINUM				LEAD		SI-AL	SEEDED		UNSEEDED: NONE	
SHAPE	SPHERE	SPHERE	SPHERE	FLAKE	SPHERE	SPHERE	SPHERE	FLAKE	SPHERE	SPHERE	SPHERE	TOTALS	DETECTION SCORE (%)		DETECTION SCORE (%)
SIZE (mm)	0.025	0.051	0.10	0.051 × 0.25	0.025	0.051	0.13	0.051 × 0.25	0.025	0.076	0.13				
PACKAGE TYPE															
TO-3	0	1	2	0	1	0	1	3	0	0	2	10 (33)	30	0 (9)	0
TO-5	3	2	2	3	0	1	1	3	2	3	1	21 (33)	64	0 (9)	0
TO-18	1	0	1	2	0	1	2	3	0	2	3	15 (33)	45	0 (9)	0
FLATPACK, METAL LID	0	0	3	0	0	0	0	0	0	1	1	5 (33)	15	0 (9)	0
FLATPACK, CERAMIC LID	0	1	1	3	0	0	0	1	0	1	1	8 (33)	24	0 (9)	0
CERAMIC DIP	0	1	1	0	0	0	0	1	0	2	0	5 (33)	15	0 (9)	0
TOTALS	4 (18)	5 (18)	10 (18)	8 (18)	1 (18)	2 (18)	4 (18)	11 (18)	2 (18)	9 (18)	8 (18)	64 (198)	32	0 (54)	0
DETECTION SCORE (%)	22	28	56	44	6	11	22	61	11	50	44		32		0

[a] The total number of specimens tested is given in parentheses.

APPENDIX I

TRIAL 10 RESULTS BY PACKAGE TYPE AND SEED PARTICLE OF PIND TESTS ON GROUP II SPECIMENS

TRIAL CONDITIONS - Frequency: 60 Hz Acceleration: $\pm 20\ g_n$ Supplier Trial

	NUMBER OF SPECIMENS FOR WHICH DETECTIONS WERE POSITIVE [a]											SEEDED		UNSEEDED	
PARTICLE	GOLD				ALUMINUM				LEAD		SI-AL			NONE	
SHAPE	SPHERE	SPHERE	SPHERE	FLAKE	SPHERE	SPHERE	SPHERE	FLAKE	SPHERE	SPHERE	SPHERE	TOTALS	DETECTION SCORE (%)		DETECTION SCORE (%)
SIZE (mm)	0.025	0.051	0.10	0.051 x 0.25	0.025	0.051	0.13	0.051 x 0.25	0.025	0.076	0.13				
PACKAGE TYPE															
TO-3	0	2	1	0	0	0	1	3	0	0	1	8 (33)	24	0 (9)	0
TO-5	3	1	2	3	0	1	1	3	3	3	1	21 (33)	64	0 (9)	0
TO-18	1	0	1	2	0	1	2	3	2	2	3	17 (33)	52	1 (9)	11
FLATPACK, METAL LID	0	0	3	0	0	0	0	0	0	1	1	5 (33)	15	0 (9)	0
FLATPACK, CERAMIC LID	1	1	1	3	0	0	2	1	0	1	1	11 (33)	33	0 (9)	0
CERAMIC DIP	0	1	1	0	0	0	0	1	0	2	0	5 (33)	15	0 (9)	0
TOTALS	5 (18)	5 (18)	9 (18)	8 (18)	0 (18)	2 (18)	6 (18)	11 (18)	5 (18)	9 (18)	7 (18)	67 (198)	34	1 (54)	2
DETECTION SCORE (%)	28	28	50	44	0	11	33	61	28	50	39		34		2

[a] The total number of specimens tested is given in parentheses.

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15. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The work described consititutes an evaluation of the test procedures and apparatus specified in MIL-STD-883, Test Method 2020, Particle Impact Noise Detection Test. The major experimental effort described — a comparision of procedures and apparatus — is based on the use of specially prepared specimen device packages known either to have or not to have a particle present. Other experimental efforts reported include characterization of the accelerations imparted to a specimen device by pre- and co-shock apparatus, a brief study of the effectiveness of couplant materials in transmitting mechanical energy to the specimen device, and a comparison of the output signal level from four different ultrasonic detection transducers under otherwise identical test conditions. As part of the plan of work, 252 of the specially prepared devices, representing six package types, were characterized (as containing particles or not) by several test procedures in order to provide a set of specimens for use by the sponsor in a proposed interlaboratory evaluation of PIND testing. Problems associated with this effort are discussed. Results of the work are presented, together with conclusions and recommendations for further work. A result of interest is that the acceleration imparted by the single sample of the pre-test shock apparatus tested is on the order of 1.5 times the maximum specified by the Test Method.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)* Acoustic emission; couplant; co-shock; detection; electronic package; impact noise; microcircuit device; particle detection; particle impact noise detection; PIND; pre-shock; seeded specimens; transducer.

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